-FINAL-
Lake Greenwood Diagnostic Study

Prepared by:
William W. Jones
Melissa Clark
Sara Peel

School of Public & Environmental Affairs
Indiana University
Bloomington, Indiana University

HUC
05120202050050

Prepared for:
Science Applications International Corporation (SAIC)
Box 28
Bloomfield, Indiana

July 2001

Lake Greenwood Diagnostic Study Executive Summary

The following is condensed from the Lake Greenwood Diagnostic Study produced by Indiana University's School of Public & Environmental Affairs, in conjunction with an Indiana Lake and River Enhancement Grant (LARE) to SAIC, Inc, the sponsors.

What is the Lake Greenwood Diagnostic Study?

The Lake Greenwood Diagnostic Study is a comprehensive examination of Lake Greenwood and its surrounding watershed. The purpose of the study was to describe the conditions and trends in Lake Greenwood and its watershed, identify potential problems, and make prioritized recommendations addressing the problems identified. This fact sheet summarizes the study results and presents some suggestions for improving water quality in Lake Greenwood.

What are Lake Greenwood and its Watershed Like?

- Lake Greenwood is an impoundment, filled in 1937, that was constructed as a recreation centerpiece of the Martin County Demonstration Project, part of President Roosevelt's 'New Deal'. It is currently part of the Crane Naval Surface Warfare Center.
- The lake is 810 acres in size with a maximum depth of 44 feet and a mean depth of 9.6 feet. A watershed of 9,453 acres drains into the lake.
- Land use within the watershed is mostly forest.

Forest	77%	Pasture	3%
Open water	9%	Residential	1%
Transitional	6%	Wetlands	<1%
Row Crop	4%		

What Kinds of Plants and Animals Live in Lake Greenwood?

- The fish – largemouth bass, bluegill, longear sunfish, warmouth, and spotted sucker dominate the fishery of Lake Greenwood.
- The Plants – Lake Greenwood supports a diverse mix of rooted plants (macrophytes) but the non-native and invasive species, Eurasian watermilfoil (EWM), dominates. EWM forms a dense canopy of growth near the surface that shades out native plants and interferes with boats. Other macrophytes include: water lily, slender naiad, spatterdock and water willow.

What Did the Diagnostic Study Find?

- Lake Greenwood is a mesotrophic, or moderately productive system. It has good water transparency and relatively sparse algal populations. There is sufficient phosphorus to promote dense algae blooms but nitrogen and light may limit additional algal growth.
- Lake Greenwood flushes, or replaces its water, about once each year. This is a relatively low flushing rate for a reservoir.
- Rooted macrophytes grow extensively in shallow waters near inlets where recent sedimentation has occurred.
- Despite the extensive forest cover, steep watershed slopes deliver water runoff at excessive velocities. This erodes many natural and manmade drainageways.
- Although shoreline erosion is less severe than in most reservoirs, there are some eroded shoreline areas.

What Improvements Can Be Made?

- Stabilize eroded culverts and drainageways – especially those near the lake. Use Best Management Practices (BMPs) to reduce runoff velocities.
- Minimize all disturbances to the stabilizing vegetative cover on steep slopes. When disturbance is necessary, BMPs should be used to their fullest extent.
- Install wetland treatment systems at suitable stream sites to help reduce runoff, sediment and nutrient loadings.
- Insure that BMPs are fully used with all forestry practices.
- Stabilize eroded shoreline areas – preferably with vegetation.
- Consider milfoil control if it interferes with other aquatic biota or recreation.
- Educate boaters about milfoil and how they can help prevent its spread.

Acknowledgements

We'd like to thank John Allen, Steve Andrews and all the rest of the Crane and SAIC staff for all the assistance they provided during the course of this study. They were a wealth of information and were extremely responsive to our requests.

The following SPEA students helped with data collection and analysis: Jessica Caplinger, Candice Crutcher, Becky Gesell, and Joel Klumpp. We couldn't have completed this study without their dedicated and professional work.

This work was supported, in part, with a Lake and River Enhancement Grant from the Indiana Department of Natural Resources Division of Soil Conservation.

TABLE OF CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

Lake Greenwood Diagnostic Study

INTRODUCTION

Lake Greenwood is a 812-acre (329-hectare) reservoir located in northern Martin County within the Naval Surface Warfare Center (NSWC) at Crane (EnviroScience 2001) (Figure 1). The maximum depth is 36 feet, the mean depth is 15.4 feet, and the lake's volume is 12,504 acre-feet. The lake lies totally within the Koleen Quadrangle on the USGS 7.5 minute topographic map. The relatively small 14.8 mi^2 (9,472 acres) watershed (Clark 1980) resides within the Koleen and Indian Springs Quadrangles. The reservoir is situated on First Creek. The east-west wind fetch is a long 3.5 miles while the longest north-south wind fetch is a little over one mile in length (Figure 2). The lake has 18.8 miles of shoreline and the shoreline development index value is 4.7. Depth-area and depth-volume relationships show that Lake Greenwood has extensive shallows (Figures 3-4).

The purpose of this Diagnostic Study was to:

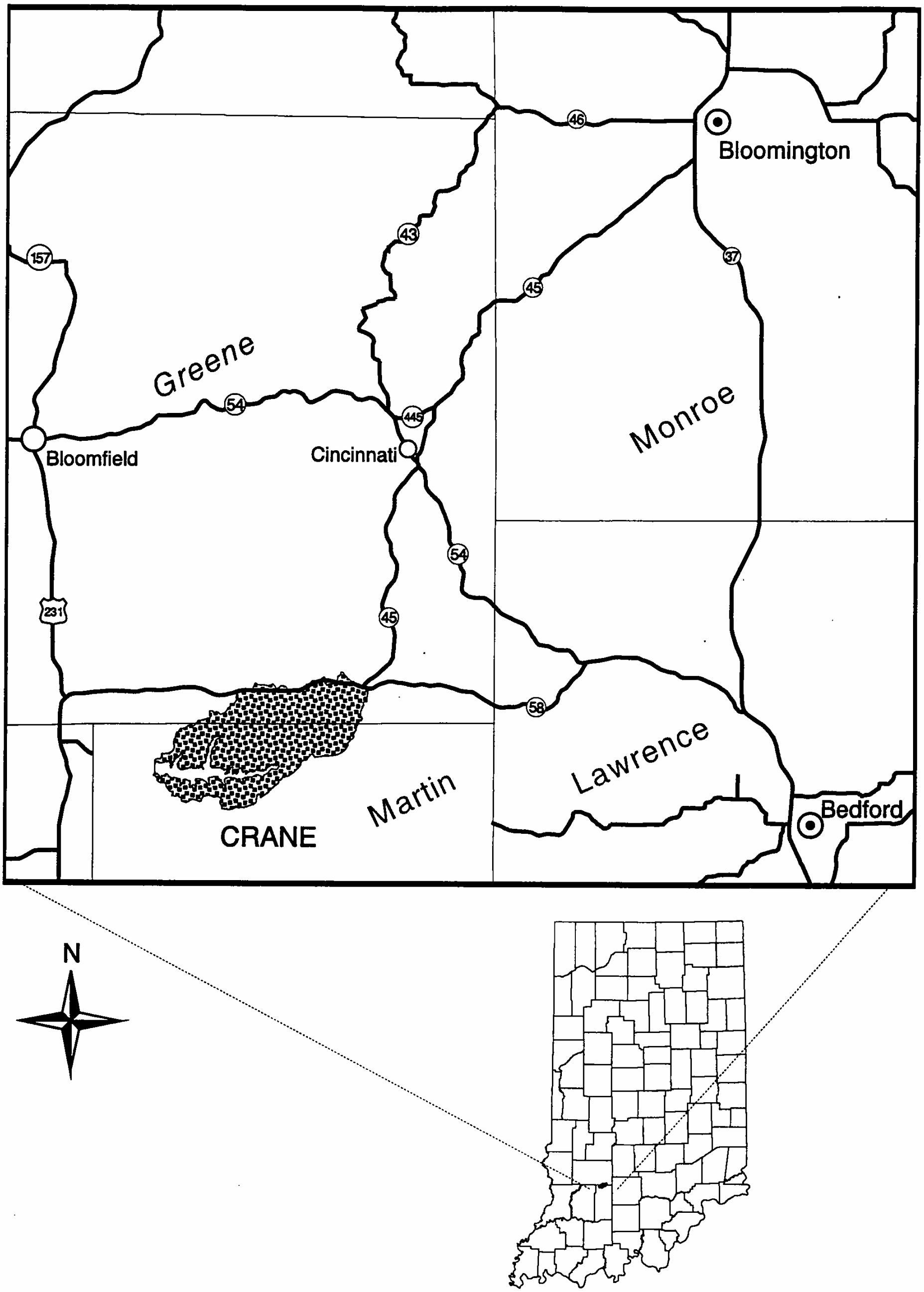
- Describe the conditions and trends in Lake Greenwood and its watershed
- Identify potential nonpoint source water quality problems
- Propose specific direction for future lake and watershed management

HISTORY

Pioneers began settling the area that became Martin County in about 1807. By 1820, when the state legislature created Martin County, the new county had about 1,032 residents (Reid and Rogers 1991). The early settlers of Martin County were primarily migrants from the Upland South – Virginia, the Carolinas, Kentucky and Tennessee. These people settled in the area because the hills and creek bottoms of northern Martin County had topography, soil, flora and fauna that resembled that from the Uplands. When they settled, they often settled near family members or friends from a previous residence. Many of these families and extended families persisted over time. Subsistence farming, attachment to the land, and the network of family and friends insulated the area from economic hardships as well as economic advances and confounded social scientists in the 1930s, who discovered that economic motivation was not of primary importance to these residents (Reid and Rogers 1991).

The Great Depression and President Franklin Roosevelt's "New Deal" response created a wide range of programs including efforts to restore higher prices for farm commodities by restricting production. The two poorest counties in Indiana, Martin and Brown, were selected as sites for the Southern Indiana Demonstration Project. Under this program, the federal government would purchase land, construct artificial lakes, and return large areas to forests. These actions were intended to take people off of land that they couldn't make a living on and relocate them to farmland where they could. The Martin County Demonstration Project encompassed 30,000 acres of land. Most of the trees on what is now the Crane property had been harvested previously and the farmland was in very poor shape. To construct the recreational centerpiece of the project, Lake Greenwood, a 1,941-foot dam was built across First Creek. In

Figure 1. Locational Map of the Lake Greenwood Watershed, CRANE, Indiana.



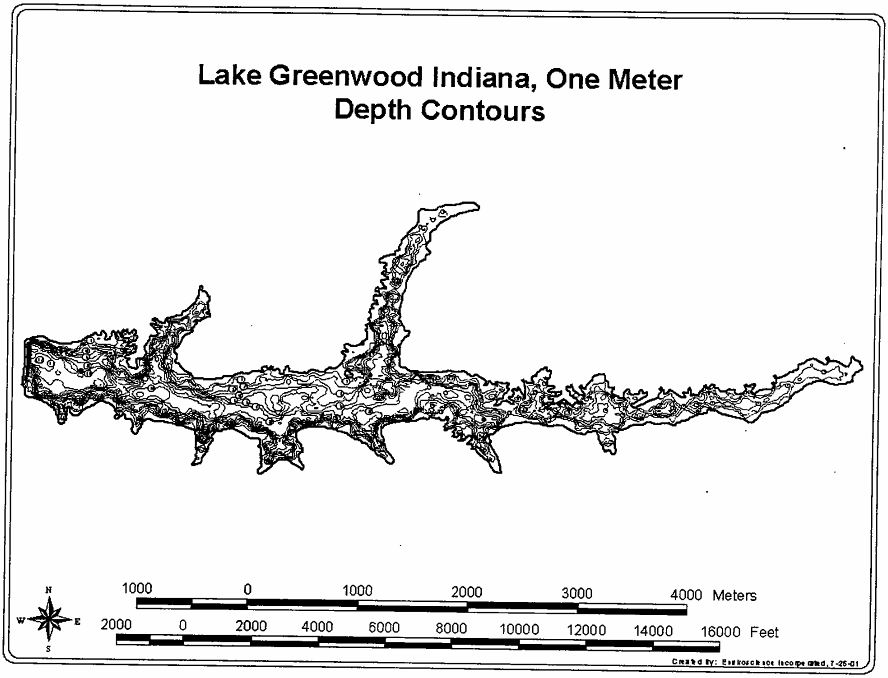


Figure 2. Bathymetric map of Lake Greenwood. Prepared by: EnviroScience, Inc., July 2001.

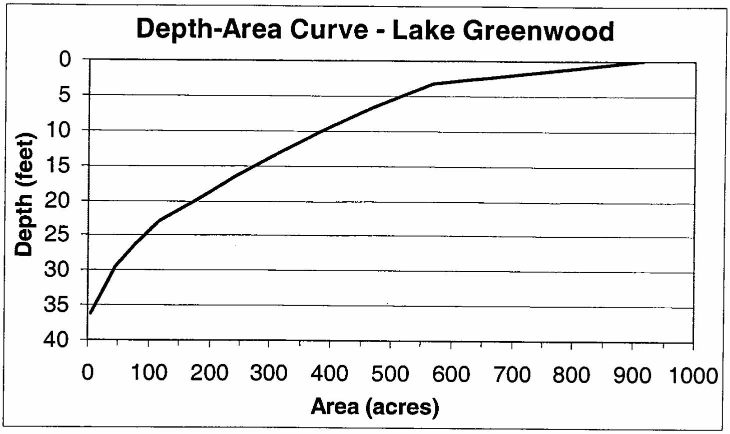


Figure 3. Depth-area curve for Lake Greenwood. Prepared By: EnviroScience, Inc., July 2001.

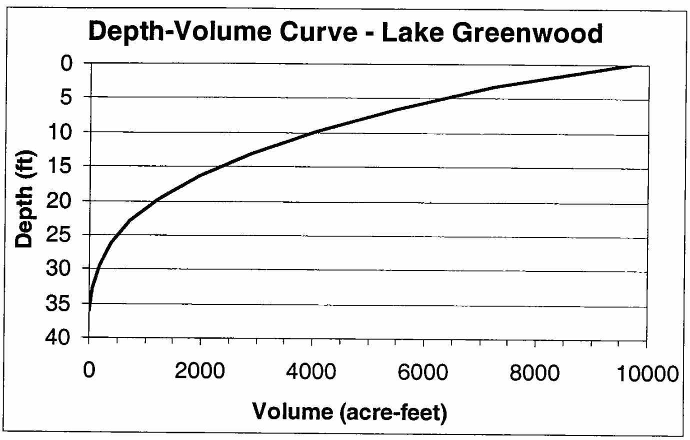


Figure 4. Depth-volume curves for Lake Greenwood. Prepared By: EnviroScience, Inc., July 2001.

the spring of 1937, Lake Greenwood began to fill. Extensive tree planting, especially near the lake, took place. The Indiana Department of Conservation took over responsibility for Lake Greenwood in 1939 (Reid and Rogers 1991).

With armed conflict in Europe and continuing Japanese aggression in East Asia, America began to prepare for war in 1940. The U.S. Congress gave the authority and funds for the Navy's long hoped for eastern ammunition depot. A catastrophic explosion at a naval ammunition depot at Lake Denmark, New Jersey in 1926 taught the navy that future depots should be in rural areas with the storage areas spread well apart to prevent chain reactions. The present site of Crane was chosen in part because it was near the planned munitions plant outside Charlestown, Indiana and because it afforded cheap land; secure water supply provided by Lake Greenwood; nearby sources of rock, limestone, and timber; an untapped labor supply; remoteness from congested areas; hilly ground that was ideal for ammunition magazines; and rail access (Reid and Rogers 1991). The selection of the site was announced in October 1940, groundbreaking occurred on January 27, 1941, and the first shipments of powder started arriving during August of that year.

Today, the NSWS Crane occupies 62,463 acres of land (Crane 1995). It is useful to note that by 1946, 332 miles of roads and 195 miles of railroads were built on the site. The depot's water system included 80 miles of water mains and 500 fire hydrants. The water treatment plant at Lake Greenwood had capacity to supply enough water for a city of 30,000. Early erosion problems required the installation of 3,864 culverts and other drainage structures during WWII (Reid and Rogers 1991).

SETTING

Geology and Soils

Lake Greenwood and its watershed lie within the Crawford Upland Physiographic Unit (Fenelon et al. 1994). Indiana has been divided into 13 such units based on similarities in topography and geology. Rocks of Pennsylvanian Age (Raccoon Creek Group) underlie the watershed area of this Unit. Within the Raccoon Creek Group rocks of the Staunton Formation are the uppermost layer. These rocks are composed of sandstone, shale, sandy shale, and minor amounts of coal, black organic-rich shale, limestone and clay (Environmental Systems Application Center 1983). The one named coal within this Group is the Seelyville Coal, which is characterized as having one of the highest sulfur contents in the state. A series of small, hillside coal mines were operated in the northern part of the watershed from the mid-1800s to around 1942 (Allen 2000). The southern most extent of Pleistocene glaciation terminated immediately to the north and east of the lake (Fenelon et al. 1994). In unglaciated areas such as Lake Greenwood and its watershed, there is very little cover over the underlying bedrock thus groundwater yields are low – having a potential yield of only 10 gallons per minute (Clark 1980).

There are 14 known caves on Crane which range in size from small crevices or pits to the 1,500 feet that has been mapped in the Aunt Liz Cave. Cave exploration is not permitted for safety reasons and to prevent disturbances to bats that inhabit some of the caves (Crane 1995).

Soils within Lake Greenwood's watershed belong to the Wellston-Gilpin mapping unit. This unit is characterized by deep and moderately deep, gently sloping to very steep, well-drained soils formed in loess and material weathered from sandstone, siltstone and shale on uplands. Wellston soils are deep and are gently sloping to very steep. Typically, they are silt loam throughout. Gilpin soils are moderately deep and are strongly sloping to very steep. Typically they have a surface layer of very dark grayish brown channery silt loam. The subsoil is yellowish brown channery silt loam and brown loam (McElrath 1988).

Because of the steep slopes (12-30%) on which they occur, the Wellston and Gilpin soils have severe limitations for building sites, agriculture, recreational development, septic systems, etc. Soils on large areas of the watershed are classified as being highly erodible (Figure 5). In fact, 77% of watershed soils are classified as highly erodible, 16% as potentially highly erodible, and only 7% are considered as not highly erodible (Held 2000). Zanesville soils, the dominant soil on the ridge tops, are less steep (2-12% slopes) and have moderated limitations for the land uses cited above (McElrath 1988). Surface elevations on the entire Crane site range from 860 feet MSL in the eastern part to 425 feet MSL in the western part (Crane 1995).

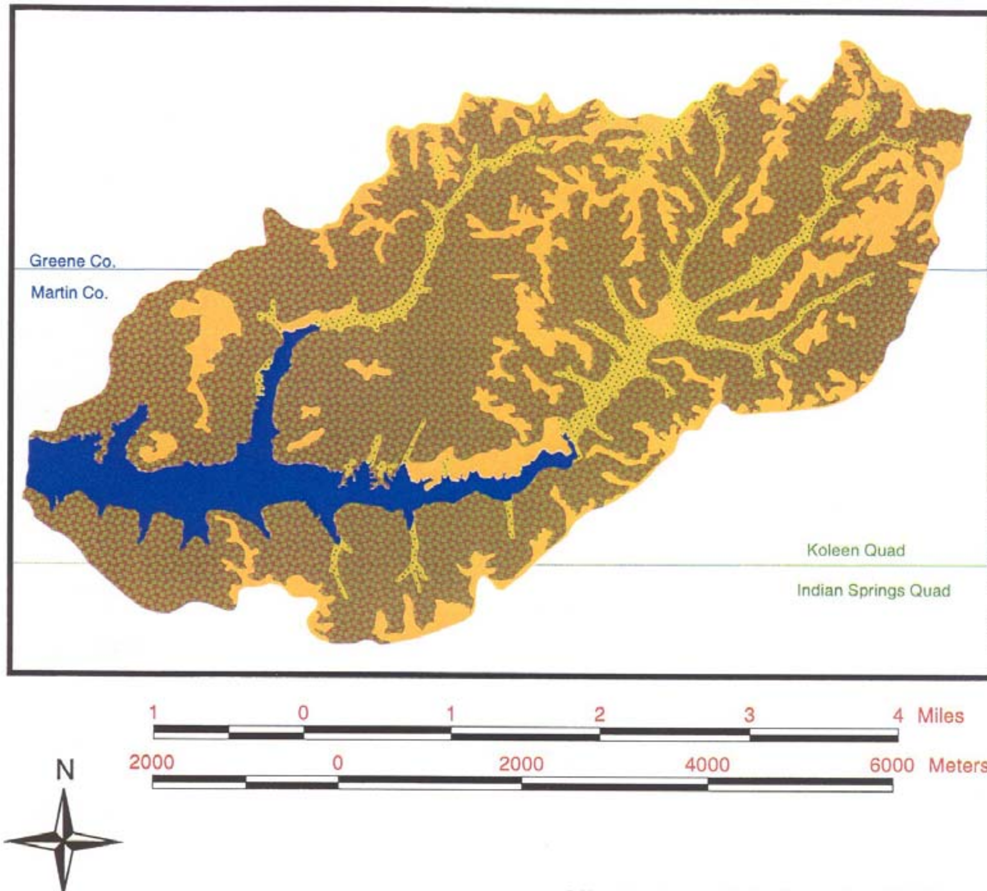
Land Use

Over 75% of Lake Greenwood's watershed area (7,004 of 9,453 total acres) is forested (Table 1; Figure 6). This is not surprising given the steep slopes and overall use of the area favor forestland. Over $1 million of timber is harvested annually from the entire Crane property (Crane 1995). A small amount of agriculture occurs but these uses are restricted to the extreme northern edge of the watershed, along State Highway 45/58, far away from the lake proper. Only a small area (9 acres) of wetlands occurs near the mouths of the major inlets to the lake (Figure 7).

TABLE 1. Land Uses in Lake Greenwood's Watershed.

Land use	%	Area (m^2)	Area (acres)
Open Water	8.58	3283200	811.3
Low intensity residential	0.07	26100	6.4
High intensity residential	0.10	39600	9.8
Commercial/industrial/transport	0.09	35100	8.7
Transitional	5.72	2187000	540.4
Deciduous Forest	74.09	28344600	7004.0
Evergreen Forest	3.49	1333800	329.6
Mixed Forest	0.06	23400	5.8
Pasture/Hay	3.45	1319400	326.0
Row Crop	4.26	1628100	402.3
Woody Wetland	0.10	36900	9.1

Figure 5. Lake Greenwood Watershed Highly Erodible Lands (HELs)



Highly Erodible Lands (HEL)

1 - Highly Erodible

2 - Potentially Highly Erodible

3 - Not Highly Erodible

Lake Greenwood

County boundaries

Quad boundaries

Sources

By: Melissa Clark
Date: 11-09-00

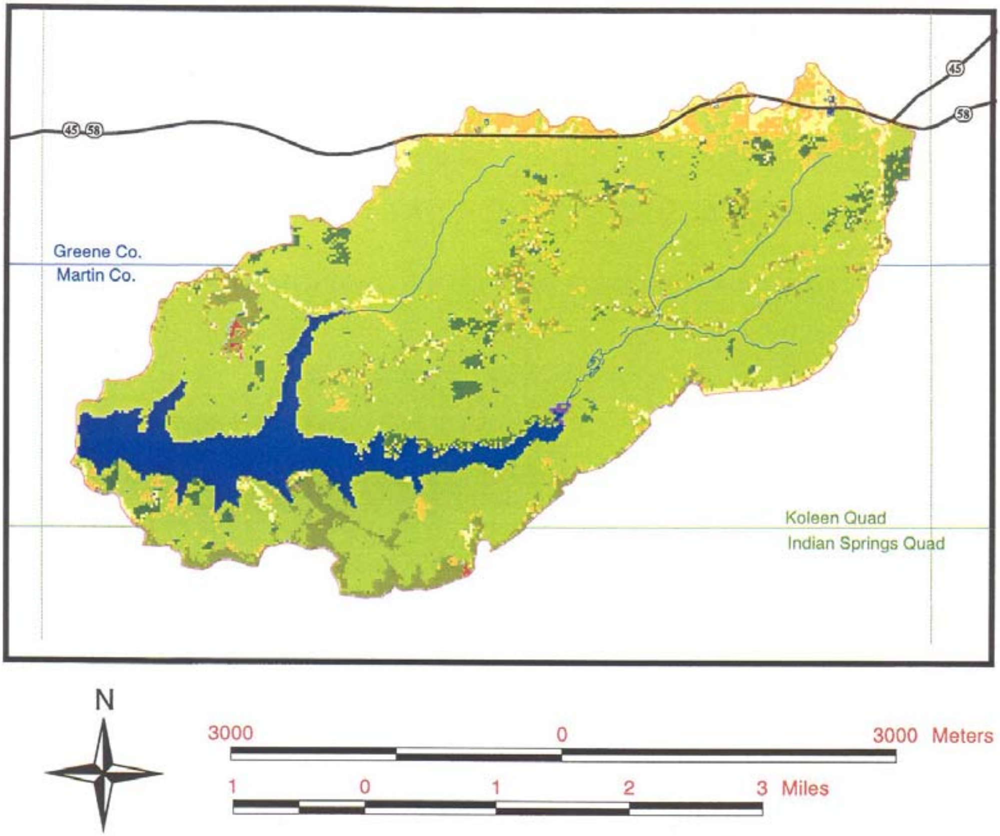
Soil Delineations: United States Department of Agriculture, Soil Conservation Service, Soil Survey of Greene County, IN, 1988

Soil Delineations: United States Department of Agriculture,Soil Conservation Service, Soil Survey of Martin County, IN, 1988

HELs designation & classifications: Martin Co. & Greene Co. USDA National Resource Conservation Services

Interior Roads: Department of Transportation, 1988.

Figure 6. Lake Greenwood Watershed Land use



Landuse and Landcover

- Open Water
- Low Intensity Residential
- High Intensity Residential
- Commercial/Industrial/Transport.
- Transitional
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Pasture/Hay
- Row Crop
- Woody Wetlands

- NWI Streams
- State Roads

- Watershed
- Quad boundaries
- County boundaries

Sources

By: Melissa Clark
Date: 08-29-2000

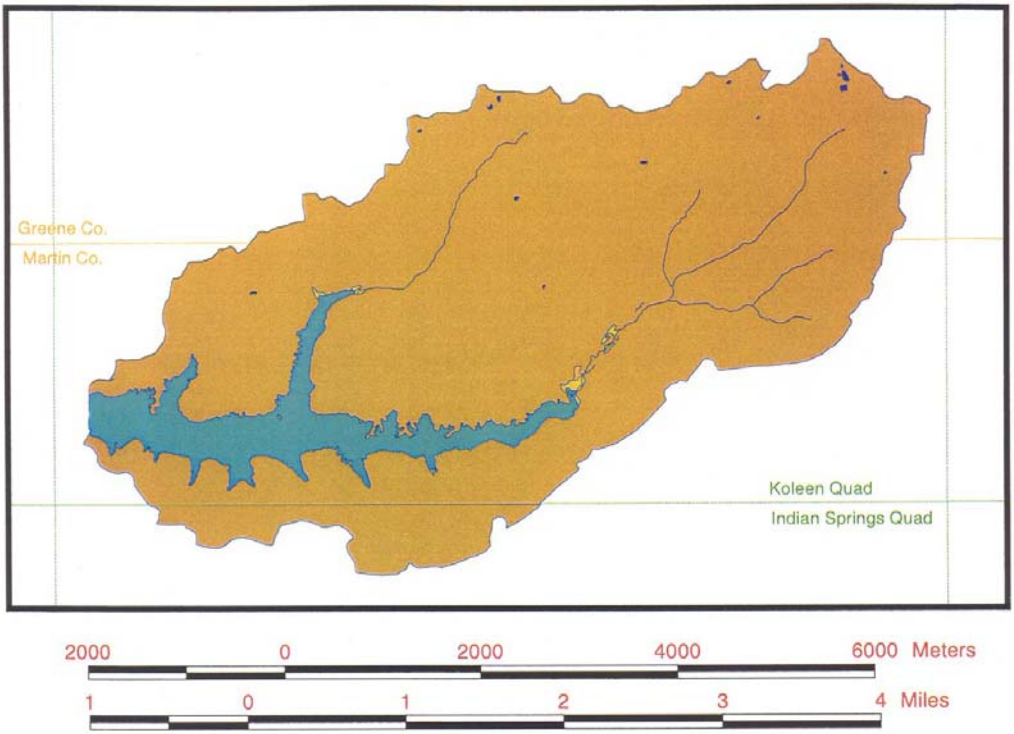
Landuse: US Geological Society, Multi-resoultion Land Characterization (MRLC), National Land Cover Data (NLCD), last updated 03-16-2000

Streams: U.S. Fish & Wildlife Service, National Wetlands Inventory (NWI) Dates range from Feb. 1971 to Dec. 1992.

Watershed boundary: National Geospatial Data Clearinghouse (NSDI) U.S. Geological Survey Node, Hydrologic Units, Jan. 29, 1996.

Roads: Department of Transporation, 1988.

Figure 7. National Wetlands Inventory (NWI) of Lake Greenwood Watershed



National Wetlands Inventory

- Lacustrine
- Palustrine emergent
- Palustrine forested
- Palustrine scrub/shrub
- Ponds
- Uplands

- NWI streams and waterboundaries
- Quad Boundaries
- County Boundaries

Sources

By: Melissa Clark
Date: 09-19-2000

Wetland Inventory & streams: U.S. Fish & Wildlife Service, National WetlandsInventory (NWI), Dates range from Feb. 1971 to Dec. 1992.

Watershed boundary: National Geospatial Data Clearinghouse (NSDI), U.S. Geological Survey Node, Hydrologic Units, 01-29-96.

Within the watershed are many miles of roads, primarily serving ammunition storage bunkers. These roads and bunkers are clearly visible on aerial photographs (Figure 8). Development is limited in Lake Greenwood's watershed. Residential areas make up only about 16 acres and commercial/industrial make up almost 9 acres. The transitional zone includes developed and semi-developed areas that include buildings, parking lots, parade grounds and other structures.

The lakeshore itself is largely undeveloped. The only structures on the shoreline include: one marina (bait shop, boat house, restroom), a water treatment intake, a boat storage building, officer's club, a bachelor quarters, a small boat house, and the commander's quarters (Allen 2000).

Recreational Lake Uses

Lake Greenwood is used for fishing, boating, skiing, sailing, and nature observation. The lake is open to the general public but permits are required for all boats using the lake and use passes are needed to enter the Crane property. In 1999, a total of 2,288 boat permits were issued (Allen 2000). Annual permits cost $15.00; 7-day permits $5.00; and daily permits $2.00 (Crane 1996). Boat traffic is not heavy on the lake. A busy day might have only 25 boats total. Two to three fishing tournaments are held on the lake annually (Andrews 2000). A hiking and biking trail circles the lake (Crane 1995).

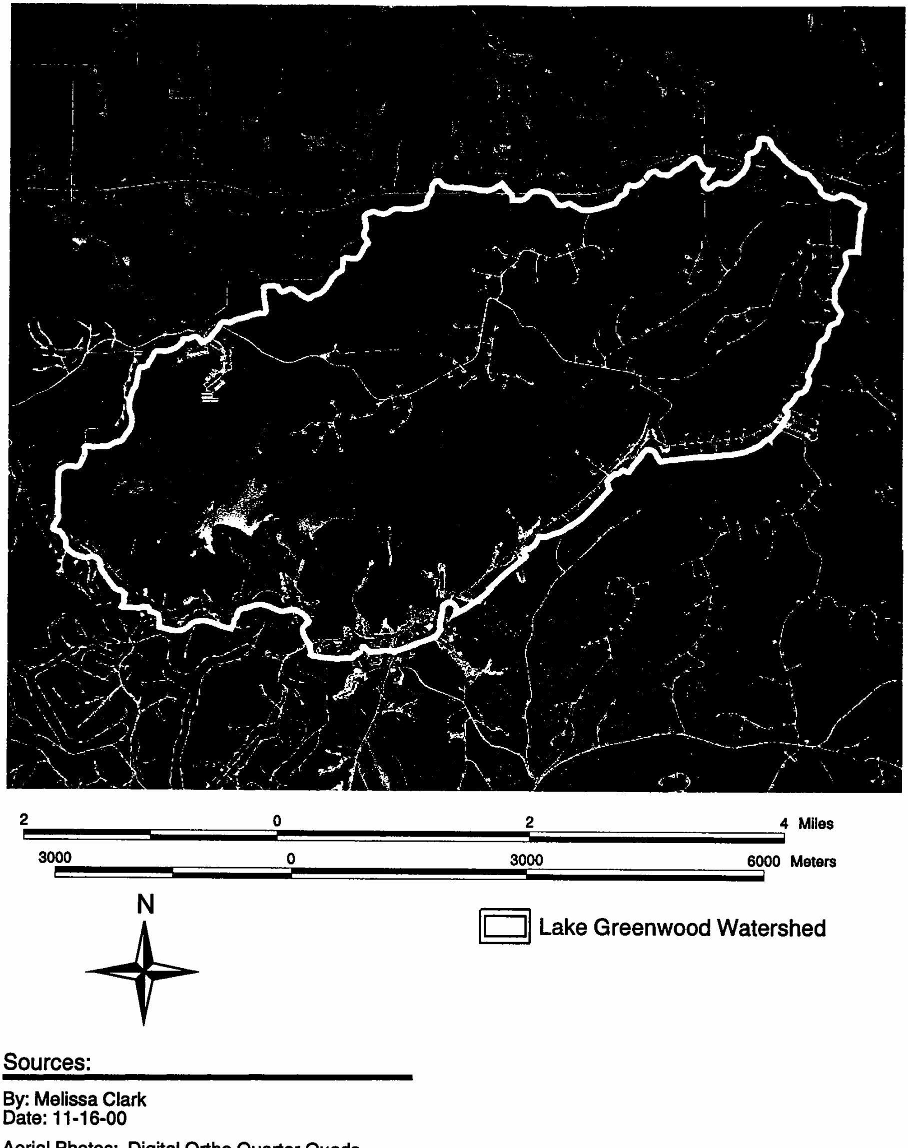
The Lake Greenwood Marina offers rentals of pontoons, Jon boats, sailboats, kayaks, canoes and paddleboats. A nearby campground offers primitive sites, full hook-ups, and family cabin tents. Boat rentals and camping are available only to Department of Defense employees and active and retired military personnel (Crane 2000).

Wildlife

The Natural Resources Office and Nature Center at Crane provides lists of animal species inventoried on the site. Nineteen amphibians have been identified and over 100 species of birds have been recorded, primarily during the Audubon Christmas Bird Count. Many waterfowl species make use of the lake. An air bubbler system has operated in a cove at the southeast side of the lake to maintain open water during winter months. Two pair of bald eagles nest on the Crane property – one pair on Lake Greenwood and the other on Lake Gallimore, one of two 30-acre flood control lakes on at Crane not open to the public. The second largest great blue heron rookery in Indiana is located along the southwest of Lake Greenwood. This rookery contains over 400 active nests (Crane 1995).

Wildlife on the site is abundant and diverse. Game species include: red and gray fox, coyote, raccoon, opossum, quail, rabbit, squirrel, turkey, ruffed grouse, woodcock, and deer. The white-tail deer herd contains about 1,800 animals. Each year, 3,000 to 4,000 hunters harvest about 550 of these deer (Crane 1995). Hunts are open to the public by means of a draw supervised by the Indiana Department of Natural Resources.

Figure 8. Lake Greenwood Watershed & Aerial Photograph



Sources:

By: Melissa Clark
Date: 11-16-00

Aerial Photos: Digital Ortho Quarter Quads, Indian Springs NW, Indian Springs NE, Koleen SW, & Koleen SE Quads.

Watershed: U.S.G.S., NRCS, & IDEM, 14-Digit Hydrologic Unit, 1999.

Significant Natural Areas or Listed Species

A review by the Indiana Natural Heritage Data Center (Hellmich 2000) identified eleven endangered, threatened or rare species from the Lake Greenwood area (Table 2). Five of the species (Henslow's Sparrow, Indiana Bat, Bald Eagle, Osprey, and Bobcat) are State endangered and the Indiana Bat is also federally endangered.

TABLE 2. Endangered, Threatened or Rare Species Found on the Crane Property.

Type	Scientific name	Common Name	Status (state/Federal)
bird	*Ammodramus henslowii*	Henslow's Sparrow	SE/**
bird	*Buteo platypterus*	Broad-winged Hawk	SSC/**
bird	*Helmitheros vermivorus*	Worm-eating Warbler	SSC/**
bird	*Mniotilta varia*	Black-and-white Warbler	SSC/**
mammal	*Myotis sodalis*	Indiana bat	SE/LE
bird	*Accipiter striatus*	Sharp-shinned Hawk	SSC/**
bird	*Haliaeetus leucocephalus*	Bald Eagle	SE/LTNL
bird	*Pandion haliaetus*	Osprey	SE/**
bird	*Wilsonia citrina*	Hooded Warbler	SSC/**
bird	*Buteo lineatus*	Red-Shouldered Hawk	SSC/**
mammal	*Lynx rufus*	Bobcat	SE/**

Key - State: SE=endangered, SSC=special concern; Federal: **=not listed, LE=endangered, LTNL=threatened.

HISTORICAL DATA

Fisheries

From 1965 to 1990, the largemouth bass-bluegill population of Lake Greenwood exhibited a trend towards increasing relative abundance of small bass and increasing abundance of large bluegill (Surprenant 1996). During 1990 the USFWS Fishery Resources Office at Carterville, IL prepared a Fisheries Management Plan for Lake Greenwood. The goal of the plan was to maintain the largemouth bass proportional stock density (PSD) at 20-40 percent and the bluegill PSD at 40-60 percent using a 12 to 15-inch protected size range on the largemouth bass (Surprenant 1996).

The most abundant species sampled during recent surveys of the lake are listed in Table 3. Because electrofishing alone can't adequately sample all possible fish species, some species are likely underrepresented by the recent surveys. Bass growth is now faster as a result of the slot size management program. There were excessive numbers of small bluegills in the lake at times in the past. The panfish fishery including bluegill is currently in good condition.

TABLE 3. Fish Species Sampled By Electrofishing in Lake Greenwood.

SPECIES	% COMPOSITION - 1990	% COMPOSITION – 1995	% COMPOSITION –2000
Bluegill	21	48	22
Largemouth bass	38	16	38
Longear sunfish	14	16	24
Spottail shiner	8	5	
Spotted sucker	<1	4	
Warmouth	4	3	4
Golden shiner	1	3	
Black crappie	<1	3	1
Emerald shiner	Not found	3	
Carp	7	2	
Channel catfish	3	2	2
Yellow perch	3	2	
Redear sunfish	2	2	1
Redfin shiner	Not found	2	

Columns do not add up to 100% due to rounding.

Water Quality

There is a general lack of water quality data available for Lake Greenwood. The lake's location within a military reserve has kept it somewhat isolated from statewide lake assessment and monitoring programs. For example, there is no volunteer on Lake Greenwood who participates in the Indiana Volunteer Lake Monitoring Program. The only existing data found in our search were several measurements made during fisheries surveys and one comprehensive lake water quality assessment conducted in 1996 under the Indiana Clean Lakes Program. These data are given in Figure 9 and Table 4 below.

The only parameters for which there is more than one measurement are Secchi disk transparency and conductivity. There is no apparent trend for these parameters over the six years of data.

Results from the 1996 lake assessment show that at that time, Lake Greenwood was not nutrient-enriched. Phosphorus, nitrogen and alkalinity concentrations are all relatively low. The lake scored a very low Indiana Trophic State Index (TSI) score of 7 (more discussion of this in the trophic state section following).

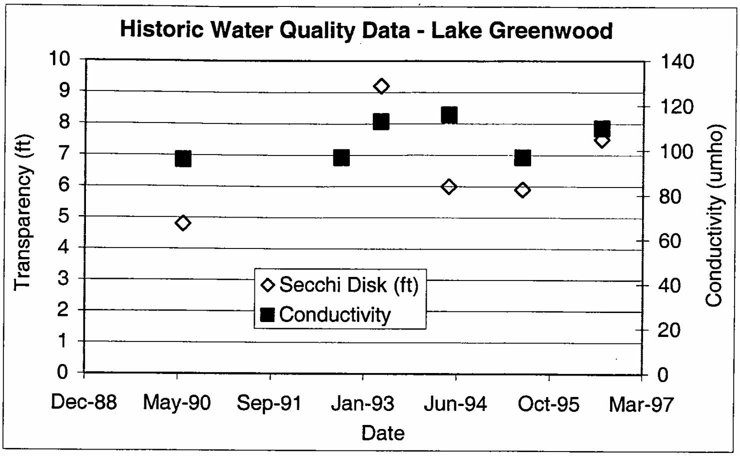


Figure 9. Historic water quality data for Lake Greenwood.
Sources: Surprenant (1996); CLP (1996)

TABLE 4. Water Quality Characteristics of Lake Greenwood, 8/12/96.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (11m)	Indiana TSI Points (based on mean values)
pH	7.2	6.7	-
Alkalinity	25.0 mg/L	27.0 mg/L	-
Conductivity	110 µmhos	108 µmhos	-
Secchi Disk Transp.	7.5 feet	-	0
Light Transmission @ 3 ft	18%	-	3
1% Light Level	18.0 feet	-	-
Total Phosphorus	0.021 mg/L	0.027 mg/L	0
Soluble Reactive Phos.	0.005 mg/L	0.005 mg/L	0
Nitrate-Nitrogen	0.022 mg/L*	0.022 mg/L*	0
Ammonia-Nitrogen	0.018 mg/L*	0.541 mg/L	0
Organic Nitrogen	0.212 mg/L	0.087 mg/L	0
Oxygen Saturation @ 5 ft.	99.12%	-	0
% Water Column Oxic	26.85%	-	2
Chlorophyll *a*	1.25 µg/L	-	-
Plankton Density	14028 per L	-	2
Blue-Green Dominance	No	-	0
		TSI Score	**7**

*method detection limit

WATERSHED INVESTIGATION

We visually inspected Lake Greenwood's watershed on several occasions to identify areas of concern. The investigations included field inspection, interviews with Crane personnel, and interviews with NRCS staff. The field inspections were conducted from accessible roads. There were many areas of the watershed within Crane that were off limits to all but authorized personnel. For example, stream Site 1 was adjacent to a gun firing range. Therefore, we did not have free access to most of the watershed.

There is no storm sewer system on the Crane site. However, as stated previously, 3,864 culverts were installed to control erosion by the mid-1940s. Nearly all of the culverts we were able to inspect on the north side of the lake were eroded on the downstream side (Figures 10 - 13). Culverts on the south side of the lake were generally more stable. In addition, we saw evidence of regular maintenance to clean out clogged culverts, especially in the area of the marina. Many of the roadside ditches having a grade are paved down to the culverts and this increases water velocities and force. Most visible stream channels had eroded banks, which is not surprising given the steep topography of the site.

Agricultural lands within the watershed lie outside the Crane site boundary. Visual inspection of these lands showed that all were in pasture rather than in row crops.

Figure 10. Many culverts suffer from erosion on the downstream side of the outlet sill. This image represents a minor example of this problem.

Figure 11. Long concrete-lined drainageways increase water velocity and force. Significant erosion and deposition has occurred at this junction of two culverts and a long drainageway along Road 331.

Figure 12. Looking downstream from Figure 11 above. The high water velocity and volume has carved a deep gully. Eroded soil flows downstream into Lake Greenwood.

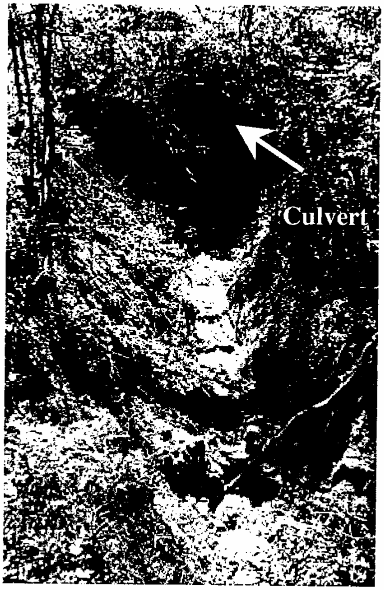


Figure 13. More than 500 feet of concrete-lined channel drains through this culvert, located to the east of the gun range on Road 331. The bottom of the metal culvert is undercut and the gully formed is six feet deep.

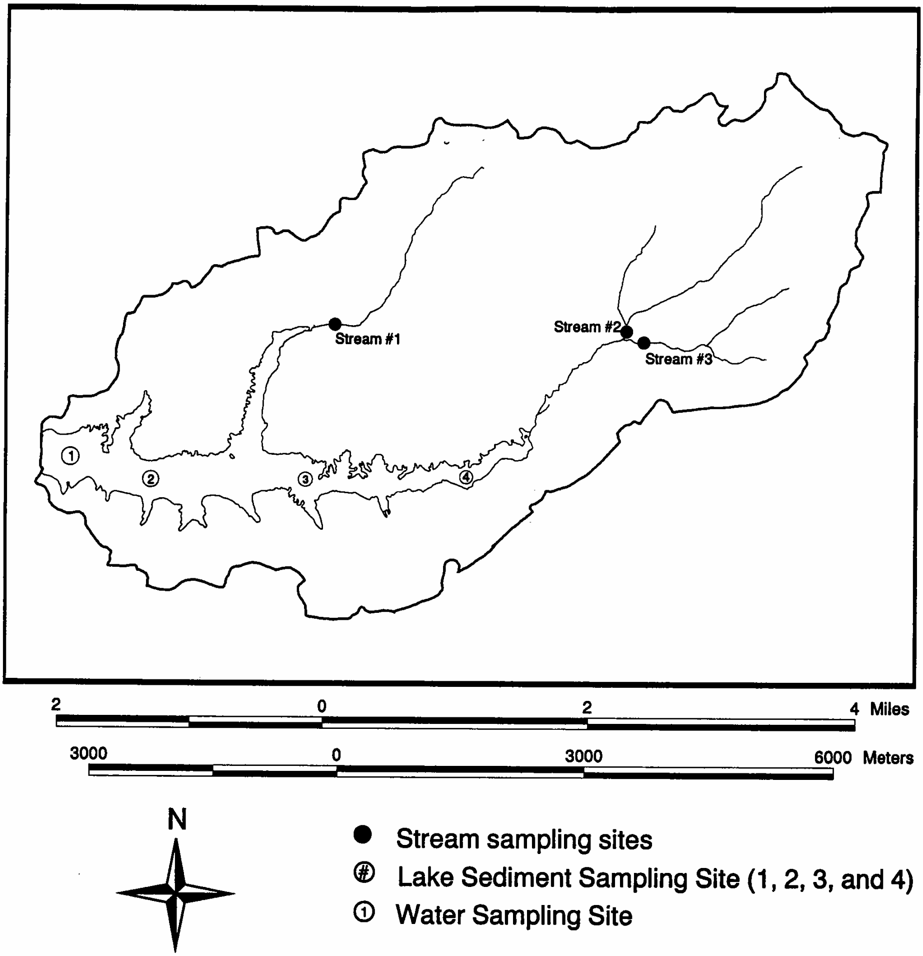
WATER QUALITY - LAKE

Methods

The water sampling and analytical methods used for Lake Greenwood were consistent with those used in IDEM's Indiana Clean Lakes Program and IDNR's Lake and River Enhancement Program. We collected water samples for various parameters on August 16, 2000 from the surface waters (***epilimnion***) and from the bottom waters (***hypolimnion***) of the lake at a location over the deepest water near the dam (Figure 14). Chlorophyll was determined only for the epilimnetic sample. Other parameters such as Secchi disk, light transmission, and oxygen saturation are single measurements made in the epilimnion. In addition, dissolved oxygen and temperature were measured at one-meter intervals from the surface to the bottom. A tow to collect plankton was made from the 1% light level to the water surface.

All sampling techniques and laboratory analytical methods were performed in accordance with procedures in *Standard Methods for the Examination of Water and* Wastewater, 19th Edition (APHA, 1995). Plankton counts were made using a standard Sedgewick-Rafter counting cell. Fifteen fields per cell were counted. Plankton identifications were made according to: Prescott (1982), Ward and Whipple (1959) and Whitford and Schumacher (1984).

Figure 14. Lake Greenwood Watershed Stream Sampling Sites and Lake Greenwood Sediment Sampling Sites.



Sources:

By: Melissa Clark
Date: 12-11-00

Watershed Boundary: U.S. Fish & Wildlife Service, National Wetlands Inventory (NWI), Dates range from Feb. 1971 to Dec. 1992.

Lake Boundary & Streams: National Geospatial Data Clearinghouse (NSDI), U.S.Geological Survey Node, Hydrologic Units, 01-29-96.

Comprehensive evaluation of lakes and streams require collecting data on a number of different, and sometimes hard-to-understand, water quality parameters. Some of the more important parameters that we analyze include:

Phosphorus. An essential plant nutrient, most often controls aquatic plant growth. Found in fertilizers, human and animal wastes, and yard waste. There are few natural sources of phosphorus to lakes and there is no atmospheric (vapor) form of phosphorus. For this reason, phosphorus is often a ***limiting nutrient*** in lakes. This means that the relative scarcity of phosphorus in lakes may limit the ultimate growth and production of algae and rooted aquatic plants. Therefore, lake management efforts often focus on reducing phosphorus inputs to lakes because: (a) it can be managed and (b) reducing phosphorus can reduce algae production.

Soluble reactive phosphorus (SRP) - dissolved phosphorus readily usable by algae. SRP is often in very low concentrations in lakes with dense algae populations where it is tied up in the algae themselves. May be released from storage in sediments when dissolved oxygen is lacking.

Total phosphorus (TP) - includes dissolved and particulate phosphorus. TP concentrations greater than 0.03 mg/L (or 30 μg/L) may cause algal blooms.

Nitrogen. An essential plant nutrient found in fertilizers, human and animal wastes, yard waste, and the air. About 80% of the air we breathe is nitrogen gas. This nitrogen can diffuse into water where it can be "fixed", or converted, by blue-green algae for their use. Nitrogen can also enter lakes and streams as inorganic nitrogen and ammonia. Because of this, there is an abundant supply of available nitrogen to lakes.

Nitrate (NO_3) - dissolved nitrogen that is converted to ammonia by algae. Found in lakes when dissolved oxygen is present, usually the surface waters.

Ammonia (NH_4) - dissolved nitrogen, preferred form for algae use. Also produced by bacteria as they decompose dead plant and animal matter. Found where dissolved oxygen is lacking, often in the hypolimnia of eutrophic lakes.

Organic Nitrogen (Org N) - includes nitrogen found in plant and animal materials. May be in dissolved or particulate form. In our analytical procedures, we analyze total Kjeldahl nitrogen (TKN). Organic nitrogen is TKN minus ammonia.

Dissolved Oxygen (DO). Dissolved gas essential for respiration of fish and other aquatic organisms. Fish need at least 3-5 parts per million (ppm) of D.O. Affects chemical reactions in water. For example, the lack of D.O. near the bottom sediments may allow dissolved phosphorus (SRP) to be released from the sediments into the water. If less than 50% of a lake's water column has oxygen, you may also see greater hypolimnetic concentrations of SRP and ammonia as well. D.O. enters water by diffusion from the atmosphere and as a byproduct of photosynthesis by algae and plants. Excessive algae growth can over-saturate (greater than 100% saturation) the water with D.O. Dissolved oxygen is consumed by respiration of aquatic organisms, such as fish, and during bacterial decomposition of plant and animal matter.

Secchi Disk Transparency. This refers to the depth to which the black & white Secchi disk can be seen in the water. Water clarity, as determined by a Secchi disk, is affected by two primary factors: algae and suspended particulate matter. Particulates (for example, soil or dead leaves) may be introduced into the water by either runoff from the land or from sediments already on the bottom of the lake. Many processes may introduce sediments from runoff; examples include erosion from construction sites, agricultural lands and riverbanks. Bottom sediments may be resuspended by bottom feeding fish such as carp, or in shallow lakes, by motorboats or strong winds.

Light Transmission. Similar to the Secchi disk transparency, this measurement uses a light meter (photocell) to determine the rate at which light transmission is diminished in the upper portion of the water column. Another important light transmission measurement is the 1% light level. The 1% light level is the water depth to which one percent of the surface light penetrates. This is considered the lower limit of algal growth.

Plankton. Plankton are important members of the aquatic food web. Include the algae (microscopic plants) and the zooplankton (tiny shrimp-like animals that eat algae). Determined by filtering water through a net having a very fine mesh (63 micron openings = 63/1000 millimeter). The plankton net is towed up through the water column from the one percent light level to the surface. Of the many different algal species present in the water, we are particularly interested in the blue-green algae. Blue-green algae are those that most often form nuisance blooms and their dominance in lakes may indicate poor water conditions.

Chlorophyll *a*. The plant pigments of algae consist of the chlorophylls (green color) and carotenoids (yellow color). Chlorophyll *a* is by far the most dominant chlorophyll pigment and occurs in great abundance. Thus, chlorophyll *a* is often used as a direct estimate of algal biomass.

Results

Results of the Lake Greenwood water assessment are included in Table 5 and Figure 15. The temperature profile (Figure 8) shows that the lake was thermally stratified on the date of sampling, although there isn't a strongly developed *hypolimnion* (bottom layer of cold water). This is often characteristic of reservoirs where a long wind fetch keeps the water circulating longer in the spring. The lengthened period of circulation allows the bottom waters to warm up prior to the onset of stratification, thus there is less of a temperature gradient between the *epilimnion* (surface mixing zone) and the hypolimnion. The hypolimnetic waters of Lake Greenwood were 12-13 °C. Hypolimnetic temperatures in natural lakes of the same depth are likely to be cooler – around 7-9 °C. The epilimnion extends from the surface down to around four meters. The boundaries for this layer are more apparent in the dissolved oxygen profile.

Lake Greenwood's epilimnion is saturated with dissolved oxygen. Photosynthesis by phytoplankton and contact with the atmosphere work to keep epilimnetic oxygen concentrations in equilibrium with those in the atmosphere. Below the mixing zone, respiration exceeds photosynthesis and thus, oxygen concentrations decline abruptly. Below seven meters, all oxygen within Lake Greenwood was consumed producing an anoxic environment.

Water quality data for Lake Greenwood are presented in Table 5. Phosphorus and nitrogen are the primary plant nutrients in lakes. Phosphorus concentrations (0.058 mg/L in the

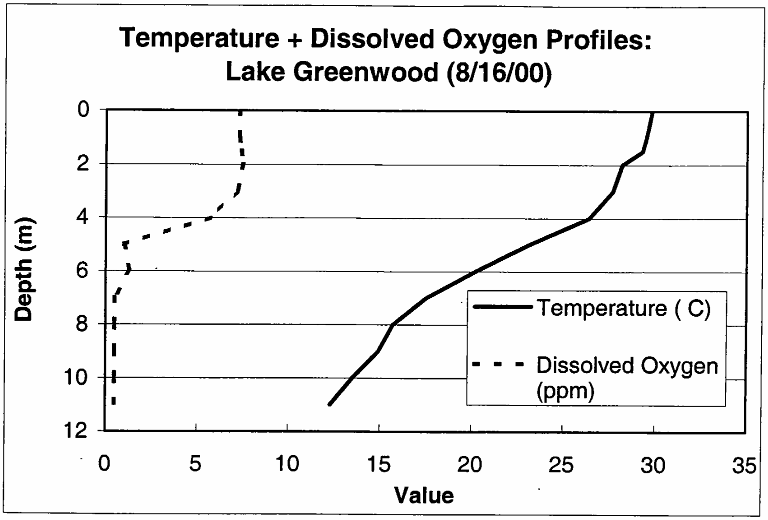


Figure 15. Temperature and dissolved oxygen profiles for Lake Greenwood.

epilimnion) are moderately high – high enough to support dense algal populations. Many productive lakes have higher concentrations of phosphorus in the hypolimnion because inorganic phosphorus (SRP) is often released from the sediments due to the anoxic, chemically reducing conditions there. There is no indication of internal loading of phosphorus in Lake Greenwood, despite the anoxia present in the hypolimnion. This leads us to conclude that there is little phosphorus enrichment of the lake's sediments. The low concentrations of inorganic nitrogen (nitrate and ammonia), the form of nitrogen used by algae, suggest that this nutrient is not available in levels sufficient to promote excess algal growth. Most of the nitrogen in the lake is occurs as organic nitrogen, meaning that it is tied up in algae or associated with other organic material. The low hypolimnetic concentration of ammonia, the primary by-product of bacterial decomposition of organic matter, indicates that organic production does not build up on the sediments. Bacterial respiration is apparently high enough to consume most of the hypolimnetic oxygen but not enough to allow the build-up of ammonia

Alkalinity is a measure of the water's ability to resist change in pH, or acid content. It is also referred to as acid neutralizing capacity or buffering capacity. This buffering action is important because it ensures a relatively constant chemical and biological environment in lakes. Alkalinity is determined largely by the availability and chemistry of carbonate in water. Sources of carbonate to natural waters include limestone (calcium carbonate) and carbon dioxide. The low alkalinity concentrations determined from our August samples indicate that Lake Greenwood is a poorly buffered system

TABLE 5. Water Quality Characteristics of Lake Greenwood, 8/16/00

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (11m)	Indiana TSI Points (based on mean values)
pH	7.4	6.5	-
Alkalinity	16.0 mg/L	22.0 mg/L	-
Conductivity	108 µmhos	101 µmhos	-
Secchi Disk Transp.	10.8 feet	-	0
Light Transmission @ 3 ft	55%	-	2
1% Light Level	18.0 feet	-	-
Total suspended solids	2.13 mg/L	5.00 mg/L	-
Turbidity	2.0 NTU	3.6 NTU	-
Total Phosphorus	0.058 mg/L	0.073 mg/L	3
Soluble Reactive Phos.	0.013 mg/L	0.013 mg/L	0
Nitrate-Nitrogen	0.022 mg/L*	0.022 mg/L*	0
Ammonia-Nitrogen	0.018 mg/L*	0.018 mg/L*	0
Organic Nitrogen	0.160 mg/L	0.224 mg/L	0
Oxygen Saturation @ 5 ft.	96%	-	0
% Water Column Oxic	54%	-	2
Chlorophyll *a*	0.64 µg/L	-	-
Plankton Density	1095 per L	-	0
Blue-Green Dominance	No	-	0
*method detection limit		**TSI Score**	7

The pH values determined from Lake Greenwood samples are relatively low. Values of pH are slightly higher in the epilimnion where the process of photosynthesis consumes carbon dioxide, a weak acid. The lack of photosynthesis in the hypolimnion, and the liberation of carbon dioxide by respiring bacteria keep pH levels lower in the hypolimnion. Conductivity values, a measure of dissolved ions, are within the normal range for Indiana lakes.

The 1% light level, which limnologists use to determine the lower limit where photosynthesis can occur, extended to a depth of 18 feet in Lake Greenwood. This is a rather deep 1% light depth for an Indiana reservoir and likely reflects the low epilimnetic total suspended solids (2.13 mg/L), turbidity (2.0 NTU) and plankton (1,095 algae per liter) concentrations. Based on the depth-area curve (Figure 3), we can see that approximately 600 acres of lake bottom (74% of total lake area) are shallower than 18 feet. This represents the area with sufficient light to support rooted plants, an area that limnologists call the *littoral zone*. Furthermore, based on the depth-volume curve (Figure 4), we see that a volume of greater than 8,000 acre-feet of Lake Greenwood (84% of total lake volume) lies above the 18-foot 1% light level. This area, referred to as the *photic zone*, represents the amount of water with sufficient light to support algae.

The interpretation of a comprehensive set of water quality data can be quite complicated. Often, attention is directed at the important plant nutrients (phosphorus and nitrogen) and to water transparency (Secchi disk) since dense algal blooms and poor transparency greatly affect the health and use of lakes. But, how much phosphorus or nitrogen is too much or, what level of transparency is too poor?

To answer these questions, limnologists must compare data from the lake in question to standards, if they exist, to other lakes, or to criteria that most limnologists agree upon. There are no nutrient standards for Indiana lakes so we must compare the Lake Greenwood results with data from other lakes and with generally accepted criteria.

Comparison With Vollenweider's Data

Results of studies conducted by Richard Vollenweider in the 1970's are often used as guidelines for evaluating concentrations of water quality parameters. His results are given in Table 6. Vollenweider relates the concentrations of selected water quality parameters to a lake's *trophic state*. The trophic state of a lake refers to its overall level of nutrition or biological productivity. Trophic categories include: *oligotrophic, mesotrophic, eutrophic* and *hypereutrophic*. Lake conditions characteristic of these trophic states are:

Oligotrophic - lack of plant nutrients keep productivity low, lake contains oxygen at all depths, clear water, deeper lakes can support trout.

Mesotrophic - moderate plant productivity, hypolimnion may lack oxygen in summer, moderately clear water, warm water fisheries only - bass and perch may dominate.

Eutrophic - contains excess nutrients, blue-green algae dominate during summer, algae scums are probable at times, hypolimnion lacks oxygen in summer, poor transparency, rooted macrophyte problems may be evident.

Hypereutrophic - algal scums dominate in summer, few macrophytes, no oxygen in hypolimnion, fish kills possible in summer and under winter ice.

The units in the table are either milligrams per liter (mg/L) or micrograms per liter (μg/L). One mg/L is equivalent to one part per million (PPM) while one microgram per liter is equivalent to one part per billion (PPB). Remember that these are only guidelines, similar concentrations in a specific lake may not cause problems if something else is limiting the growth of algae or rooted plants.

Values for Lake Greenwood are indicated by the asterisk (*) in Table 6 following. The total phosphorus concentration exceeds the mean concentration for mesotrophic lakes but was less than the mean concentration for eutrophic lakes. The total nitrogen and chlorophyll concentrations measured in Lake Greenwood are much lower than the mean concentration for oligotrophic lakes.

TABLE 6. Mean values of some water quality parameters and their relationship to lake production. (after Vollenweider, 1979)

PARAMETER	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Total Phosphorus (mg/L or PPM)	0.008	0.027 *	0.084	>0.750
Total Nitrogen (mg/L or PPM)	* 0.661	0.753	1.875	-
Chlorophyll *a* (µg/L or PPB)	* 1.7	4.7	14.3	-

Comparison With Other Indiana Lakes

A wide variety of conditions, including geography, morphometry, time of year, and watershed characteristics, can influence the water quality of lakes. Thus, it is difficult to predict and even explain the reasons for the water quality of a given lake. To help place lake data into perspective, consider the following data for 355 Indiana lakes collected during July and August 1994-98 under the Indiana Clean Lakes Program (Table 7). The set of data summarized in the table represent mean values of epilimnetic and hypolimnetic samples for each of the 355 lakes.

The Lake Greenwood results for ammonia, total Kjeldahl nitrogen, total phosphorus, soluble reactive phosphorus and chlorophyll are all less than the median values for the Indiana lakes included in the table. The total Kjeldahl nitrogen concentration for Lake Greenwood is actually lower than the lowest TKN concentration observed in the 355 Indiana lakes used for comparison.

TABLE 7. Water Quality Characteristics of 355 Indiana Lakes Sampled From 1994 thru 1998 by the Indiana Clean Lakes Program. Means of epilimnion and hypolimnion samples were used.

	Secchi Disk (m)	NO_3 (mg/L)	NH_4 (mg/L)	TKN (mg/L)	Total Phos (mg/L)	SRP (mg/L)	Chl. *a* (µg/L)
Median	1.8	0.025	0.472	1.161	0.097	0.033	5.33
Maximum	9.2	9.303	11.248	13.794	4.894	0.782	230.9
Minimum	0.1	0.022	0.018	0.230	0.001	0.001	0
Mean Values for Lake Greenwood	**3.3**	**0.022**	**0.018**	**0.210**	**0.066**	**0.013**	**0.64**

Using a Trophic State Index

The large amount of water quality data collected during lake water quality assessments can be confusing to evaluate. Because of this, Indiana and many other states use a trophic state index (TSI) to help evaluate water quality data. A TSI condenses water quality data into a single, numerical index. Different index (or eutrophy) points are assigned for various water quality concentrations. The index total, or TSI, is the sum of individual eutrophy points for a lake.

The Indiana TSI. The Indiana TSI ranges from 0 to 75 total points. The TSI totals are grouped into the following three lake quality classifications:

TSI Total	Water Quality Classification
0-15	highest quality (oligotrophic)
16-30	intermediate quality (mesotrophic)
31-45	low quality (eutrophic)
46-60	lowest quality (hypereutrophic)

A rising TSI score for a particular lake from one year to the next indicates that water quality is worsening while a lower TSI score indicates improved conditions. However, natural factors such as climate variation can cause changes in TSI score that do not necessarily indicate a long-term change in lake condition. Parameters and values used to calculate the Indiana TSI are given in Table 8.

The Indiana TSI has not been statistically validated, tends to rely too heavily on algae and does not weight poor transparency or nutrients high enough in the total score. For these reasons, the Carlson TSI may be more appropriate to use in evaluating Indiana lake data.

The Indiana Trophic State Index value calculated for Lake Greenwood is 7 (see Table 5). This value falls within the "highest quality" range of the index. Of 355 lake assessments conducted under the Indiana Clean Lakes Program between 1994 and 1998, only 26 had Indiana TSI scores less than Lake Greenwood.

The Carlson TSI. The most widely used and accepted TSI is one developed by Bob Carlson called the Carlson TSI. Carlson analyzed summertime total phosphorus, chlorophyll *a*, and Secchi disk transparency data for numerous lakes and found statistically significant relationships among the three parameters. He developed mathematical equations for these relationships and these for the basis for the Carlson TSI. Using this index, a TSI value can be generated by one of three measurements: Secchi disk transparency, chlorophyll *a* or total phosphorus. Data for one parameter can also be used to predict a value for another. The TSI values range from 0 to 100. Each major TSI division (10, 20, 30, etc.) represents a doubling in algal biomass (Figure 16).

As a further aid in interpreting TSI results, Carlson's scale is divided into four lake productivity categories: oligotrophic (least productive), mesotrophic (moderately productive); eutrophic (very productive) and hypereutrophic (extremely productive).

TABLE 8. The Indiana Trophic State Index

Parameter and Range			Eutrophy Points
I.	Total Phosphorus (ppm)		
	A.	At least 0.03	1
	B.	0.04 to 0.05	2
	C.	0.06 to 0.19	3
	D.	0.2 to 0.99	4
	E.	1.0 or more	5
II.	Soluble Phosphorus (ppm)		
	A.	At least 0.03	1
	B.	0.04 to 0.05	2
	C.	0.06 to 0.19	3
	D.	0.2 to 0.99	4
	E.	1.0 or more	5
III.	Organic Nitrogen (ppm)		
	A.	At least 0.5	1
	B.	0.6 to 0.8	2
	C.	0.9 to 1.9	3
	D.	2.0 or more	4
IV.	Nitrate (ppm)		
	A.	At least 0.3	1
	B.	0.4 to 0.8	2
	C.	0.9 to 1.9	3
	D.	2.0 or more	4
V.	Ammonia (ppm)		
	A.	At least 0.3	1
	B.	0.4 to 0.5	2
	C.	0.6 to 0.9	3
	D.	1.0 or more	4
VI.	Dissolved Oxygen: Percent Saturation at 5 feet from surface		
	A.	114% or less	0
	B.	115% 50 119%	1
	C.	120% to 129%	2
	D.	130% to 149%	3
	E.	150% or more	4

Table 8 continued

VII.	Dissolved Oxygen: Percent of measured water column with at least 0.1 ppm dissolved oxygen	
	A. 28% or less	4
	B. 29% to 49%	3
	C. 50% to 65%	2
	D. 66% to 75%	1
	E. 76% 100%	0
VIII.	Light Penetration (Secchi Disk)	
	A. Five feet or under	6
IX.	Light Transmission (Photocell) : Percent of light transmission at a depth of 3 feet	
	A. 0 to 30%	4
	B. 31% to 50%	3
	C. 51% to 70%	2
	D. 71% and up	0
X.	Total Plankton per liter of water sampled from a single vertical tow between the 1% light level and the surface:	
	A. less than 3,000 organisms/L	0
	B. 3,000 - 6,000 organisms/L	1
	C. 6,001 - 16,000 organisms/L	2
	D. 16,001 - 26,000 organisms/L	3
	E. 26,001 - 36,000 organisms/L	4
	F. 36,001 - 60,000 organisms/L	5
	G. 60,001 - 95,000 organisms/L	10
	H. 95,001 - 150,000 organisms/L	15
	I. 150,001 - 5000,000 organisms/L	20
	J. greater than 500,000 organisms/L	25
	K. Blue-Green Dominance: additional points	10

Using Carlson's index, a lake with a summertime Secchi disk depth of 1 meter would have a TSI of 60 points (located in line with the 1 meter). This lake would be in the mesotrophic category. Because the index was constructed using relationships among transparency, chlorophyll, and total phosphorus, a lake having a Secchi disk depth of 1 meter would also be expected to have 20 μg/L chlorophyll and 43 μg/L total phosphorus.

Not all lakes have the same relationship between transparency, chlorophyll and total phosphorus as Carlson's lakes do. Other factors such as high suspended sediments or heavy predation of algae by zooplankton may keep chlorophyll concentrations lower than might be otherwise expected from the total phosphorus or chlorophyll concentrations. High suspended sediments would also make transparency worse than otherwise predicted by Carlson's index.

CARLSON'S TROPHIC STATE INDEX

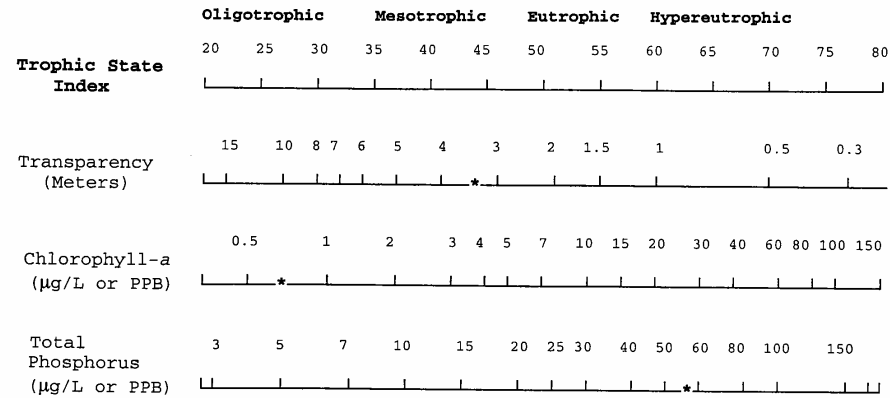


Figure 16. Carlson's Trophic State Index with Lake Greenwood values indicated by (*). This is similar to the results comparing our data with Vollenweider's data and is, we believe, a better measure of the true trophic status of Lake Greenwood.

It is also useful to compare the actual trophic state points for a particular lake from one year to the next to detect any trends in changing water quality. While climate and other natural events will cause some variation in water quality over time (possibly 5-10 trophic points), larger point changes may indicate important changes in lake quality.

Analysis of Lake Greenwood transparency and chlorophyll *a* data according to Carlson's TIS shows that these parameters register in the mesotrophic categories (see asterisks in figure above). The phosphorus data fall within the hypereutrophic range.

Other Parameters

Plankton. The plankton population at the time of our sampling was very sparse. Diatoms and yellow-brown algae dominated it. Blue-green algae, the algal group most often associated with nuisance blooms, accounted for only 32% of the total number of cells in our sample.

Algae like most green plants depend on light and several important nutrients for their growth. If any of the essentials needed for growth are in limited supply, algal growth will not achieve its maximum rate. The material in least supply is known as growth limiting. Generally, among the two major nutrients, an N : P atomic ratio near 16 : 1 is considered to be optimal for algal growth while less than 10 : 1 would indicate a nitrogen-deficient state (Aldridge et al.

1993). The total nitrogen : total phosphorus ratio measured in August in Lake Greenwood was 3 : 1. Thus, at the time of sampling, Lake Greenwood was nitrogen limited – a rare occurrence in Indiana lakes. The primary sources of nitrogen to lakes are runoff and biological fixation. Many blue-green algae are nitrogen fixers (convert N_2 into inorganic nitrogen) and this can be an important source of nitrogen to many lakes. Lake Greenwood's plankton population was only 32% blue-greens.

Summary. From the data collected, we can conclude that Lake Greenwood is a rather unproductive lake with regards to algae and essential algal nutrients. The trophic state of the lake hasn't changed much since the only other comprehensive assessment of the lake in 1996. The Indiana TSI score for both assessments was only 7. There were differences in score distribution between the two assessments, however. In 1996, the samples were taken during an algae bloom and TSI points were assigned to algal density and poorer light transmission. In 2000, algal densities were very low but TSI points were assigned for higher total phosphorus concentrations.

Higher phosphorus concentrations in Lake Greenwood are troubling as additional phosphorus can stimulate increased algal growth in phosphorus-limited lakes. However, because Lake Greenwood was nitrogen-limited at the time of sampling, this additional phosphorus did not stimulate algal production. Higher hypolimnetic ammonia concentrations in the 1996 assessment drove the mean total nitrogen : total phosphorus ratio to 17.8 : 1, which indicated phosphorus limitation at that time.

Our working model for Lake Greenwood is that the lake isn't overly productive. The products of that productivity are consumed largely by decomposers before they can build up in the sediments. The higher algal productivity in 1996 resulted in increased hypolimnetic ammonia concentrations, the primary by-product of bacterial decomposition. A consequence of this heterotrophic process, oxygen is consumed. However, despite the anoxia, no phosphorus was released from the sediments.

Our concern is that increased nitrogen can flip Lake Greenwood to a phosphorus-limited system with a resulting increase in algal production. The long-term consequences of this is decreased transparency, increased anoxia, and build-up of organic matter in the sediments.

AQUATIC PLANT SURVEY AND SHORELINE ANALYSIS

Methods

On August 16, 2000, we conducted a survey of rooted vegetation and shoreline erosion in Lake Greenwood by slowly traversing the entire shoreline area of the lake in our sampling boat. Vegetation stands were identified and noted on enlarged maps of the lake. When needed, plant samples were collected with a double-tined rake for identification in the boat. Plant identifications were made using Fink (1994), Borman et al. (1997) and Nichols (1999). Eroded shoreline areas were marked on separate maps.

Results

A map showing the overall vegetation of the entire lake is shown in Figure 17. More detailed maps of the western, middle, and eastern sections of Lake Greenwood are shown in Figures 18-20. Areal coverage of rooted aquatic plants is given in Table 9. Overall, rooted vegetation covered nearly 260 acres or about 32% of the lake's surface area.

The most abundant rooted plant in Lake Greenwood is Eurasian watermilfoil (*Myriophyllum spicatum*). This species occurs throughout the lake, especially in shallow coves. Large stands of the plant also occur on shallow, offshore bars in the east and central sections of the reservoir. Eurasian watermilfoil is an invasive species that is probably the number one nuisance plant species in midwestern lakes. It can grow in depths greater than 4m, shows no substrate preference, and is not turbidity tolerant (Nichols 1999). It forms a dense surface canopy that effectively blocks out light to shorter native species. Milfoil can spread by small fragments cut by motorboats or wind shearing.

Fragrant water lily (*Nymphaea odorata*) is the next most abundant rooted plant in the lake. The median depth of water in which this plant grows is one meter. It shows no substrate or turbidity preference (Nichols 1999).

For the most part, the shoreline of Lake Greenwood is stable. Areas of shoreline erosion are indicated in Figures 18-20. Our best estimate is that there is less than 600 feet of eroded shoreline needing stabilization. Most individual areas observed were relatively short sections (30 feet) and 3 to 6 feet high. However, several areas on the south side of the lake west of the marina (Figure 19-20) have eroded banks exceeding 10 feet in height.

Discussion

Diverse, moderately dense stands of aquatic plants are desirable in a lake's littoral zone. Emergent aquatic plant communities protect the shoreline from erosion by dampening the force of waves and stabilizing shoreline soils. Vegetation can also provide screening for the lakeshore resident or user and buffer noise from motorboats. Many species of aquatic plants, such as the fragrant water lily and pickerelweed, are aesthetically pleasing because they have showy flowers or interesting shapes. Aquatic vegetation also provides fish habitat and spawning sites, waterfowl cover and food, and habitat for aquatic insects. For example, sedges (*Carex* spp.) become spawning beds for northern pike in spring, wild rice beds (*Zizania aquatica*) attract shorebirds in summer, and wild celery (*Vallisneria americana*) develops tubers that attract canvasbacks in fall and is one of the finest fish food and cover plants (Engel, 1988). Table 10 lists positive attributes of some aquatic plant species.

Non-native plants often do not have these positive attributes and can be overly aggressive in crowding out native species. The dense upper canopy that Eurasian watermilfoil produces is known to crowd out native species. The fact that this species now accounts for more than 64% of the rooted aquatic plant stands in Lake Greenwood is evidence of this.

TABLE 9. Lake Greenwood Littoral Vegetation.

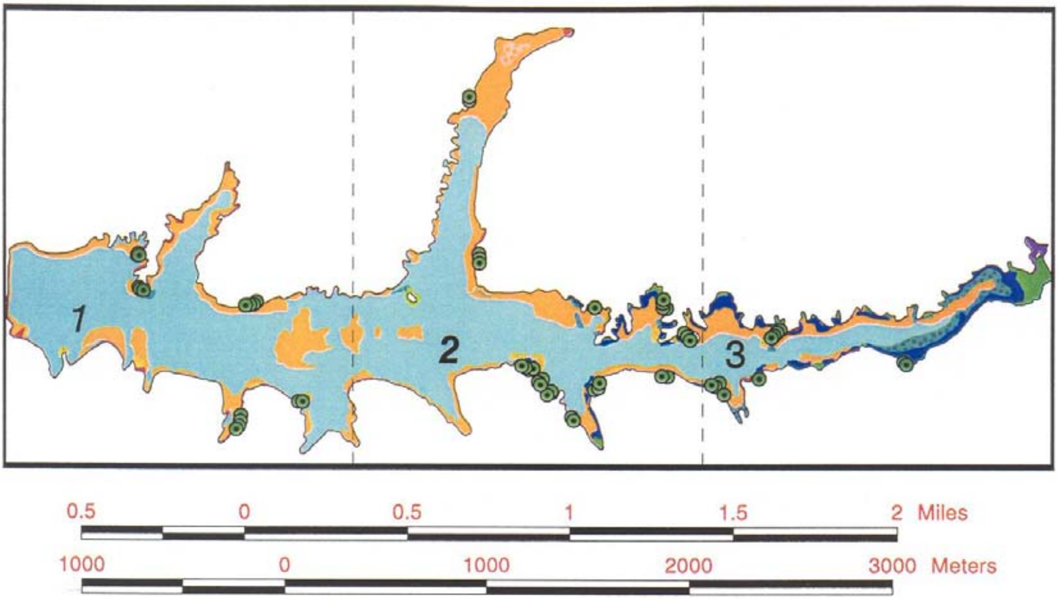
Vegetation Type	Area m^2	Area (acres)	%
American waterwillow	43,379	10.71	4.12
Rushes	2,013	0.50	0.19
Eurasian watermilfoil	679,478	167.83	64.58
Sedges	2,024	0.50	0.19
Slender naiad	74,798	18.48	7.11
Rushes/Sedges (50/50)	7,699	1.90	0.73
Water-thread pondweed	181	0.04	0.02
E. watermilfoil/Slender naiad (50/50)	12,627	3.12	1.20
Spatterdock	57,561	14.22	5.47
Fragrant water lily	14,0281	34.65	13.33
Vallisneria	15,994	3.95	1.52
Chara	4,612	1.14	0.44
Broad-leaf cattail	11,151	2.75	1.06
American pondweed	402	0.10	0.04
TOTAL	1,052,200	259.89	100

TABLE 10. Attributes of a Vegetated Shoreline Buffer

POSITIVE ATTRIBUTES	RECOMMENDED PLANT TYPES
Shoreline erosion control	Grasses, emergents
Wave dampening	Emergents
Screening	Emergents, shrubs
Shade	Trees
Noise buffer	Emergents, shrubs
Aesthetics	Pretty flower or plant form
Fish cover	Submergents, floating leaved
Fish spawning	Varies
Animal cover	Emergents, shrubs
Animal nest sites	Varies
Animal food	Varies
Macroinvertebrate habitat	Submergents

Source: Klessig and Jones (1986)

Figure 17. Lake Greenwood Littoral Vegetation & Shoreline Erosion



1 *Map #1 - Detail of littoral vegetation & shoreline erosion.*

2 *Map #2 - Detail of littoral vegetation & shoreline erosion*

3 *Map #3 - Detail of littoral vegetation & shoreline erosion*

Shoreline Erosion

Lake Greenwood Littoral Vegetation

- American Waterwillow
- Eurasian Water-milfoil
- Brittle Naiad
- E. Water-milfoil/Brittle Naiad (50/50)
- Fragrant Water-lily
- Spatterdock
- Vallisneria
- Water-thread Pondweed
- American Pondweed
- Chara
- Rushes
- Sedges
- Rushes/Sedges (50/50)
- Broad-leaf Cattail
- Open Water

Sources

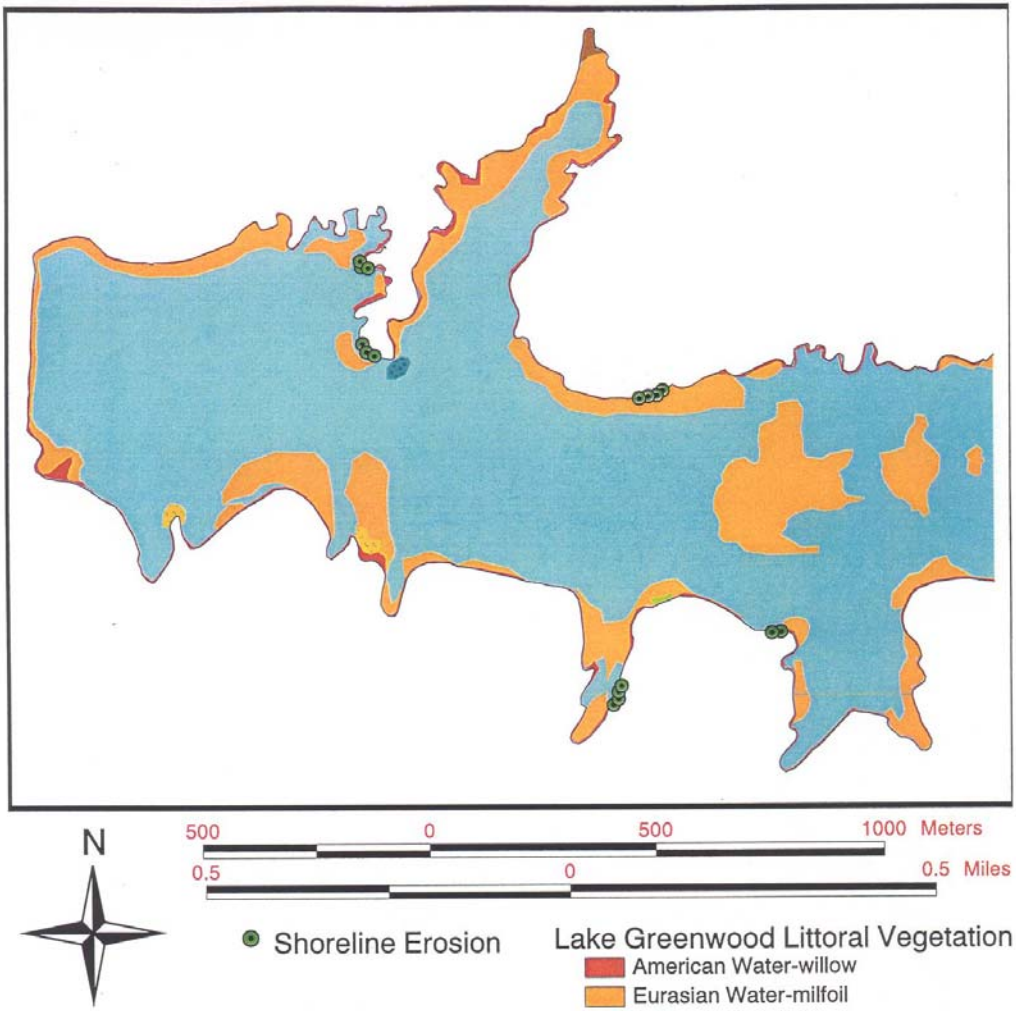
By: Melissa Clark
Date: 10-18-00

Lake Greenwood Shoreline boundary from NWI: U.S. Fish & Wildlife Service, National Wetlands Inventory (NWI), Dates range from Feb. 1971 to Dec. 1992.

Littoral Vegetation Data collected on 08-16-00, By Bill Jones, Melissa Clark, & Sara Peel.

Shoreline Erosion Data collected on 08-16-00, By Bill Jones.

Figure 18. Lake Greenwood Littoral Vegetation & Shoreline Erosion #1



Shoreline Erosion

Lake Greenwood Littoral Vegetation

- American Water-willow
- Eurasian Water-milfoil
- Brittle Naiad
- E. Water-milfoil/Brittle Naiad (50/50)
- Fragrant Water-lily
- Spatterdock
- Vallisneria
- Water-thread Pondweed
- American Pondweed
- Chara
- Rushes
- Sedges
- Rushes/Sedges (50/50)
- Broad-lead Cattail
- Open Water

Sources

By: Melissa Clark
Date: 10-18-00

Lake Greenwood Shoreline boundary from NWI: U.S. Fish & Wildlife Service, National Wetlands Inventory (NWI), Dates range from Feb. 1971 to Dec. 1992.

Littoral Vegetation Data collected on 08-16-00, By Bill Jones, Melissa Clark, & Sara Peel.

Shoreline Erosion Data collected on 08-16-00, By Bill Jones.

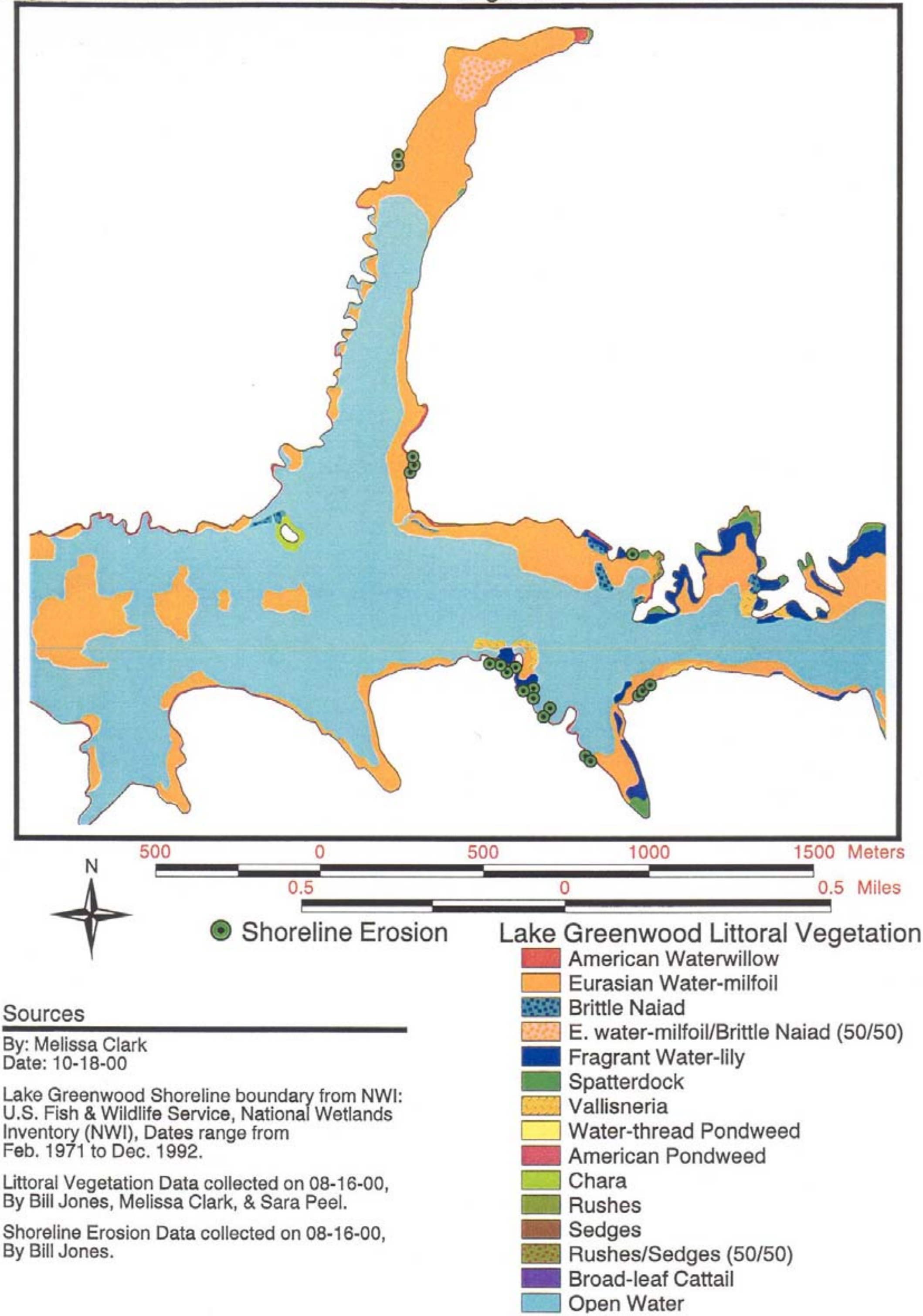
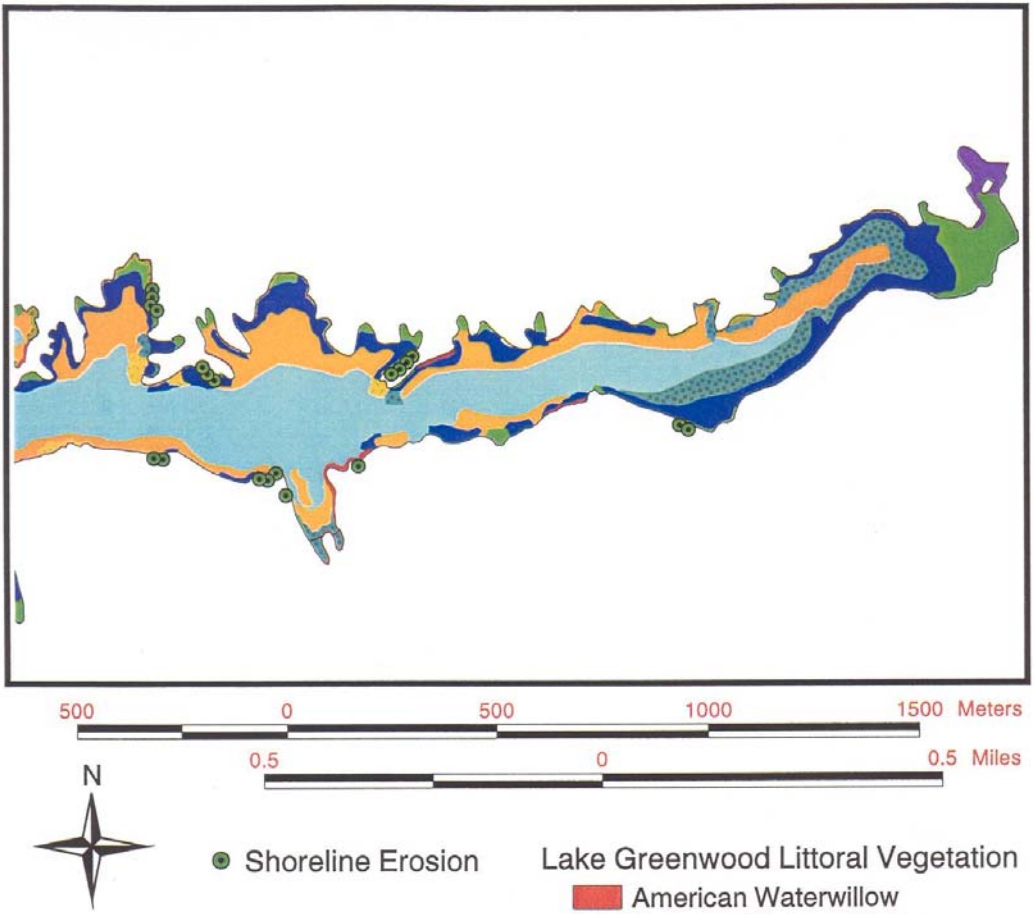


Figure 19. Lake Greenwood Littoral Vegetation & Shoreline Erosion #2

Figure 20. Lake Greenwood Littoral Vegetation & Shoreline Erosion #3



● Shoreline Erosion

Lake Greenwood Littoral Vegetation

- American Waterwillow
- Eurasian Water-milfoil
- Brittle Naiad
- E. Watermilfoil/Brittle Niad (50/50)
- Fragrant Water-lily
- Spatterdock
- Vallisneria
- Water-thread Pondweed
- American Pondweed
- Chara
- Rushes
- Sedges
- Rushes/Sedges (50/50)
- Broad-leaf Cattail
- Open water

Sources

By: Melissa Clark
Date: 10-18-00

Lake Greenwood Shoreline boundary from NWI: U.S. Fish & Wildlife Service, National Wetlands Inventory (NWI), Dates range from Feb. 1971 to Dec. 1992.

Littoral Vegetation Data collected on 08-16-00, By Bill Jones, Melissa Clark, & Sara Peel.

Shoreline Erosion Data collected on 08-16-00, By Bill Jones.

LAKE SEDIMENTS

Methods

Surficial sediment samples were collected from Lake Greenwood at four different sites along the length of the lake (Figure 14). The samples were collected using an Ekman dredge, then transferred into glass jars and kept in a cooler filled with ice.

In the laboratory, the following was determined for each sample: particle size distribution, percent organic matter, total phosphorus and total Kjeldahl nitrogen. Particle size was determined using hydrometers according to ASTM methods. Organic matter content of the dried sediment samples was determined by weight loss following ashing in a muffle furnace at 550^0C for four hours. Total phosphorus and total Kjeldahl nitrogen was determined following cupric sulfate digestion on an Alpkem FLOW Solution Autoanalyzer Model 3570.

Particle Size

The particle size distribution of a sediment sample defines the percentage amounts of the different size ranges in the sediment (by dry weight). The common classification of sedimentary particles was devised by C.K. Wentworth in 1922 according to the following (Twenhofel, 1950):

Name of Particles	Dimensions, mm
Boulder	256 or above
Cobble	64 to 256
Pebble	4 to 64
Granule	2 to 4
Very coarse sand grain	1 to 2
Coarse sand grain	0.5 to 1
Medium sand grain	0.25 to 0.5
Fine sand grain	0.125 to 0.25
Very fine sand grain	0.0625 to 0.125
Silt particle	3.9×10^{-3} to 0.0625
Clay particle	Smaller than 3.9×10^{-3}

Lake Greenwood's sediments have a relatively large percentage of sand-sized particles (Table 11). This is likely due to the primary parent material of local soils – sandstone and shale. Since clay is only a minor component of the local soils, there is less clay in the sediments compared to sand or silt. Nevertheless clay still ranges between 17% and 24% in the sediments of the lake. Fine clay particles have a very slow settling rate and thus, stay in suspension in the water column for a long time. It takes very little energy from water movements to overcome the low density of these particles to prevent their settling. For example, a coarse clay with a settling rate of 0.0015 cm/sec, would take 11.7 days to settle through five feet of absolutely calm, undisturbed water.

TABLE 11. Textural Analysis of Lake Greenwood Sediment - 8/16/00.

Sample	% Sand	% Clay	% Silt
1	59.2	21.4	19.4
2	69.2	16.8	14.0
3	41.2	23.8	35.0
4	38.2	18.4	43.4

Often in long reservoirs having a single major inlet, the largest soil particles drop out initially because it takes more energy to keep them suspended. As the water moves through the lake, losing energy along the way, finer particles drop out. This creates a gradient of larger to smaller particles from the inlet to the outlet. However, we observed little pattern such as this in particle size in Lake Greenwood sediments. Apparently the various small side channels along the lake deliver enough sand- and silt-sized particles to maintain relative homogeneity in particle size along the lake.

Organic Matter

The percentage of organic matter content in lake sediments can be an indicator of organic production in the lake. It also reflects organic matter inputs from watershed runoff. In 'healthy' lakes not suffering from excessive productivity, organic matter is sufficiently decomposed in the water column and at the sediments that it does not accumulate in the sediments. In over productive lakes, more organic matter is produced than can be handled by the heterotrophic organisms and organic matter accumulates. Hasler (1969) termed such lakes as 'physiologically senile", in that they produce more food than they can consume.

The organic matter content of Lake Greenwood sediments is shown in Table 12. Concentrations range from 9% at Site 1 near the dam/outlet to 5.2% at Site 4 near the inlet. In hypereutrophic Cedar Lake, Indiana, organic matter content of surficial sediments ranged from 17-20% (Echelberger et al. 1984). The organic matter content of Monroe Reservoir sediments ranged from only 2.1-3.5 % (Jones et al. 1997). Lake sediments generally have a higher organic matter content than do reservoir sediments. In a study of sediments from six lakes and four reservoirs in Indiana, the mean organic matter content of lake sediments was 10.1% while that of reservoir sediments was 1.9 % (Orme and Nelson 1979). This may be due to the generally greater flushing rate of reservoirs, which can keep sediments better oxidized, can wash out particulates before they have time to settle out, and can dilute organic sediments with mineral materials from watershed erosion.

The high (for reservoirs) organic content of Lake Greenwood's sediments and the gradient from the dam to the inlet can be explained by the potential sources of organic matter. Although algal productivity is relatively low in Lake Greenwood, there is a significant amount of rooted aquatic vegetation present. The senescence of these plants each Fall is an important source of organic matter, nitrogen and phosphorus to the lake. We would also expect that significant organic material loading to the lake would derive from runoff from the steep, forested slopes of the watershed. Such terrestrial organic matter tends to be more resistant to

TABLE 12. Organic Content of Lake Greenwood Sediment – 8/16/00.

Sample	%
1	9.0%
2	5.6%
3	6.5%
4	5.2%
4 dup	5.2%

decomposition than internally produced (autochthonous) sources of organic matter. Thus, this resistant organic matter can build up in the sediments and the fine organic matter can move with the water flow down the lake to the outlet.

Nitrogen and Phosphorus

Sediment-bound nutrients represent a potential pool of nutrients that can, under certain circumstances, be released back into the water column to nourish algae. Unfortunately, there are no guidelines for assessing the amounts of nutrients in lake sediments.

Nitrogen and phosphorus concentrations in Lake Greenwood sediment samples are shown in Table 13. These concentrations are consistent with those measured in other Indiana lake and reservoir sediments. For example, Orme and Nelson (1979) report mean total phosphorus and total nitrogen concentrations in lake sediments as 0.71 mg/g and 6.89 mg/g respectively and 0.72 mg/g and 1.77 mg/g respectively in reservoir sediments. The phosphorus concentrations we found in Lake Greenwood's sediments are somewhat lower than these other values while the nitrogen levels are somewhat higher. Leaves and other allochthonous sources are relatively nitrogen-rich and phosphorus-poor so we might expect higher nitrogen and lower phosphorus concentrations in Lake Greenwood sediments due to these materials.

There is an apparent gradient of higher to lower sediment nitrogen concentrations as one goes from the outlet east toward the inlet. Since nitrogen is strongly coupled with organic matter, and sediment organic matter concentrations followed a similar trend, these results are consistent.

TABLE 13. Nutrient Content of Lake Greenwood Sediments – 8/16/00.

Sample	Phosphorus (mg/g)	Nitrogen (mg/g)
1	0.081	10.509
1 dup	0.098	-
2	0.517	5.545
3	0.134	6.069
3 dup	-	5.990
4	0.123	4.596
4 dup	0.123	4.721

STREAM ANALYSES

Methods

At each stream site, we measured temperature, dissolved oxygen and conductivity *in situ* with a YSI Model 85 meter. In addition, we collected water samples from just below the water surface using a cup sampler for the following parameters:

- pH
- alkalinity
- total phosphorus (TP)
- soluble reactive phosphorus (SRP)
- nitrate-nitrite (NO_3)
- ammonia (NH_4)
- total organic nitrogen
- total suspended solids (TSS)

These samples were placed into the appropriate bottle with preservative (if needed) and stored in an ice chest until analysis in SPEA's laboratory. The SRP sample was filtered in the field through a Whatman GF-C filter.

Discharge was determined using a Flo-Mate Current Meter (Marsh-McBirney). The stream was divided into at least 15 cross-sections for which depth and width were determined. The velocity within each cross-section was measured with the current meter.

Water. The major streams flowing into Lake Greenwood were sampled twice during this project. The samples collected on 5/24/00 were at base flows while those collected on 8/8/00 were during a runoff event. The stream sampling sites are shown on Figure 14 and included:

Little First Creek at Road 331 (Site 1)
First Creek at Road 290 (Site 2)
South Fork First Creek at Road H-301 (Site 3)

At each stream site, water was analyzed for the same parameters as the lake with the addition of fecal coliform bacteria. In addition, discharge was determined using a Flo-Mate Current Meter (Marsh-McBirney).

Macroinvertebrate Community Assessment. Macroinvertebrates were collected using the multi-habitat approach detailed in the USEPA Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers, 2nd ed. (Barbour et al. 1999). This method was supplemented by qualitative picks from substrate and surface netting. Two researchers collected macroinvertebrates for 20 minutes, for a total of 40 minutes of collection effort. The macroinvertebrate samples were processed using the laboratory processing protocols detailed in the same manual. We identified macroinvertebrates to the family level. We selected the family level approach based on a recommendation for doing so from the Indiana Department of

Environmental Management (IDEM), increased organism identification certainty, and several studies which support the adequacy of family level analysis (Furse et al. 1984, Ferraro and Cole 1995, Marchant 1995, Bowman and Bailey 1997, Waite et al. 2000).

The family-level Hilsenhoff Biotic Index (HBI) was calculated from the macroinvertebrate results. Aquatic macroinvertebrates are important indicators of environmental change. The insect community composition can reflect water quality; research shows that different macroinvertebrate orders and families react differently to pollution sources. Some are tolerant while others are intolerant of organic pollution. Based on this, Hilsenhoff and others have assigned tolerance values to a number of macroinvertebrate families. To calculate the HBI, the number of organisms present is multiplied by their family tolerance value, the products are summed and divided by the total number of organisms for which tolerance values are available (Hilsenhoff 1988). In addition to the HBI, macroinvertebrate results were analyzed by number of taxa, percent dominant taxa, EPT Index, EPT count to total number of individuals, and the EPT count to Chironomid count. EPT refers to the three insect orders dominated by largely intolerant families: Ephemeroptera, Plecoptera, and Trichoptera. These six metrics were scored using the IDEM macroinvertebrate Index of Biotic Integrity (mIBI) (IDEM 1996). Indexes of biotic integrity based on macroinvertebrates are valuable because the residual effects of nutrients and sediment are most apparent in measures of biological community performance because of the ability of aquatic biota to integrate cumulative effects of multiple events (Ohio EPA 1999).

Stream Results

Water. Results of the stream sampling are included in Tables 14 and 15. Alkalinity and pH values were very low for both sampling events – evidence of the relative lack of carbonates and other alkalinity-producing materials in the watershed's bedrock. Nutrient concentrations are also low although storm runoff transported nitrates from the watershed. Conductivity is lower during the runoff event because the water flowing more quickly over the land has less time to dissolve ions. Total suspended solids were higher during the runoff event as runoff water is more erosive and can transport solids more readily. The high turbidity and TSS at Site 2 in May was due to an unknown substance that imparted a 'milky' appearance in the water.

In a recent study of 85 relatively undeveloped basins across the United States, the USGS reported the following median concentrations: ammonia (0.020 mg/L), nitrate (0.087 mg/L), total nitrogen (0.26 mg/L), orthophosphate (0.010 mg/L), and total phosphorus (0.022 mg/L) (Clark et al. 2000). Our results for the Lake Greenwood streams are closely aligned with these reported values and allow us to conclude that the Lake Greenwood streams are of relatively high quality.

Little First Creek was actually the widest and deepest of the three creeks (Figure 21). Our sampling site on this creek is influenced by the water level in Lake Greenwood as this site is the closest to the lake. During the base flow sampling, the creek was filled with water but there the velocity was not measurable. At the time of the storm event sampling, Little First Creek had the greatest discharge of the three stream sites.

TABLE 14. Results For Stream Sampling – Base Flow (5/24/00).

Parameter	Site 1	Site 2	Site 3
Discharge (cfs)	0	0.114	0.047
pH	6.4	6.4	6.3
Alkalinity (mg/L)	7	15	8.5
Turbidity (NTU)	1.7	14.5	1.4
Total Suspended Solids (mg/L)	0.8	8.4	1.5
Conductivity (mmhos)	137.5	139.8	124.5
Temperature (°C)	19.5	19.8	17.1
Dissolved Oxygen (mg/L)	8.92	8.09	9.45
Total Phosphorus (mg/L)	0.02	0.034	0.007
Soluble Reactive Phos. (mg/L)	0.014	0.014	0.016
Nitrate-Nitrogen (mg/L)	0.047	0.040	0.018
Ammonia-Nitrogen (mg/L)	0.018*	0.018*	0.018*
Organic Nitrogen (mg/L)	0.212*	0.212*	0.212*

* method detection limit

TABLE 15. Results for Stream Sampling – Storm Flow (8/8/00).

Parameter	Site 1	Site 2	Site 3
Discharge (cfs)	44.22	31.75	17.15
PH	7	6.8	6.7
Alkalinity (mg/L)	12	11	21
Turbidity (NTU)			
Total Suspended Solids (mg/L)	6.2	15.2	6.2
Conductivity (mmhos)	62	74	78
Temperature (°C)	17.2	17.2	17
Dissolved Oxygen (mg/L)	9.25	10.1	8.9
Total Phosphorus (mg/L)	0.025	0.047	0.016
Soluble Reactive Phos. (mg/L)	0.013	0.013	0.011
Nitrate-Nitrogen (mg/L)	0.11	0.101	0.06
Ammonia-Nitrogen (mg/L)	0.018*	0.018*	0.018*
Organic Nitrogen (mg/L)	0.212*	0.212*	0.212*

*method detection limit

Macroinvertebrates. Results of the macroinvertebrate analyses are shown in Tables 16 – 18. The residual effects of nutrients and sediment are most manifest in measures of biological community performance because of the ability of aquatic biota to integrate cumulative effects of multiple events (Ohio EPA 1999). For this reason, when considering the health of the creeks in the Lake Greenwood watershed, biotic data are often the most reliable measure.

Site 1 contained Isopods, which, for the most part, are scavengers, associated with large organic debris particles such as leaves (McCafferty 1983). The dipteran families found at this site are predators generally associated with low currents. Both are tolerant of organic pollution. Despite this, EPT families dominated all the sampling sites on Little First Creek and First Creek. Since these EPT families are generally intolerant of organic pollution, this confirms the results of the water analyses.

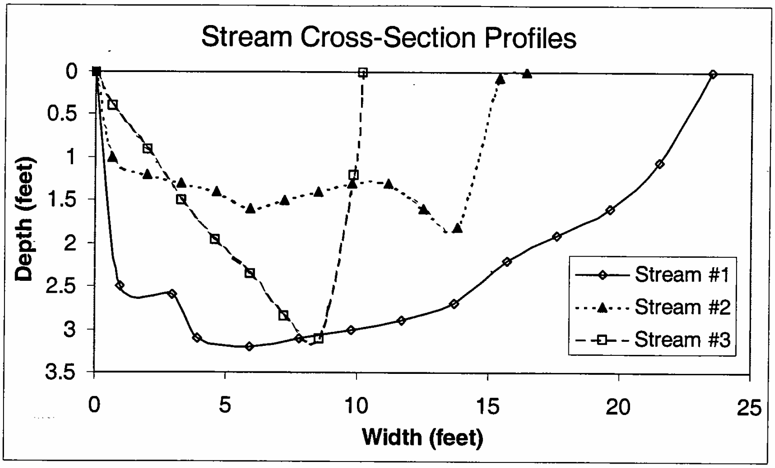


Figure 21. Cross-section profiles of the streams sampled at storm flow.

TABLE 16. Stream #1 Multi-habitat macroinvertebrate results, 5/24/00.

Order	Family	#
Diptera	Sciomyzidae	1
Diptera	Tabanidae	6
Ephemeroptera	Heptageniidae	1
Ephemeroptera	Baitiscidae	4
Ephemeroptera	Ephemerellidae	6
Ephemeroptera	Baetidae	1
Ephemeroptera	Siphonuridae	1
Isopoda	Asellidae	13
Plecoptera	Perliidae	4
Plecoptera	Capniidae	3
Tricoptera	Psychomyiidae	3

Table 17. Stream #2 Multi-habitat macroinvertebrate results, 5/24/00.

Order	Family	#
Anisoptera	Macromiidae	1
Coleoptera	Dystiscidae	9
Coleoptera	Halipidae	7
Coleoptera	Halipidae	4
Ephemeroptera	Siphlonuridae	1
Ephemeroptera	Baetidae	1
Hemiptera	Gerridae	1
Plecoptera	Perlidae	13
Plecoptera	Tricorythidae	6
Plecoptera	Lepidostomatidae	1

Table 18. Stream #3 Multi-habitat macroinvertebrate results, 5/24/00.

Order	Family	#
Coleoptera	Haliplus	4
Ephemeroptera	Siphlonuridae	1
Ephemeroptera	Heptageniidae	4
Ephemeroptera	Leptophlebiidae	59
Ephemeroptera	Ephemerellidae	1
Gammaridae	Gammarus	1
Hemiptera	Gerridae	1
Plecoptera	Peridae	2
Plecoptera	Peridae	13
Plecoptera	Nemouridae	1
Plecoptera	Chloroperlidae	1
Plecoptera	Perlodidae	1
Tricoptera	Psychanyiidae	1

The macroinvertebrate data are compared to mIBI classification scores used by the Indiana Department of Environmental Management in Table 19. Scores of 0-2 indicate the sampling site is severely impaired; scores of 2-4 indicate the site is moderately impaired, scores of 4-6 indicate the site is slightly impaired, and scores of 6-8 indicate that the site is non-impaired. The low numbers of organisms we collected gave low scores for 'Number of Individuals' and 'EPT Count'. IDEM's sampling protocol requires collecting 200 organisms minimum and we could not collect that many organisms using our level of effort protocol. However, scores for the remaining metrics are in the upper ranges that suggest only slight to no impairment. The dominance of the intolerant EPT taxa even resulted in a low score for 'Percent Dominant Taxa' – a diversity indicator.

TABLE 19. Scoring Criteria for the Family Level Macroinvertebrate Index of Biotic Integrity with Scores for Stream Sites Indicated in Bold. Higher Classification Scores Indicate Higher Quality Streams.

		CLASSIFICATION SCORE			
LAKE GREENWOOD STREAM #1	**0**	**2**	**4**	**6**	**8**
Family Level HBI	≤5.63	5.62- 5.06	5.05-4.55	4.54-4.09 **4.429**	≥4.08
Number of Taxa	≤7	8-10	11-14 **11**	15-17	≥18
Number of Individuals	≤79 **43**	129-80	212-130	349-213	≥350
Percent Dominant Taxa	≤61.6	61.5-43.9	43.8-31.2	31.1-22.2 **30.2**	≥ 22.1
EPT Index	≤2	3	4-5	6-7	≥8 **8**
EPT Count	≤19	20-42 **23**	43-91	92-194	≥195
EPT Count To Total Number of Individuals	≤0.13	0.14-0.29	0.30-0.46	0.47-0.68 **53.4%**	≥0.69

		CLASSIFICATION SCORE			
LAKE GREENWOOD STREAM #2	**0**	**2**	**4**	**6**	**8**
Family Level HBI	≤5.63	5.62- 5.06	5.05-4.55	4.54-4.09	≥4.08 **1.6**
Number of Taxa	≤7	8-10	11-14 **10**	15-17	≥18
Number of Individuals	≤79 **44**	129-80	212-130	349-213	≥350
Percent Dominant Taxa	≤61.6	61.5-43.9	43.8-31.2	31.1-22.2 **29.5**	≥ 22.1
EPT Index	≤2	3	4-5 **5**	6-7	≥8
EPT Count	≤19	20-42 **22**	43-91	92-194	≥195
EPT Count To Total Number of Individuals	≤0.13	0.14-0.29	0.30-0.46	0.47-0.68 **50.0%**	≥0.69

TABLE 19 (continued)

		CLASSIFICATION SCORE			
LAKE GREENWOOD STREAM #3	0	2	4	6	8
Family Level HBI	≤5.63	5.62- 5.06	5.05-4.55	4.54-4.09	≥4.08 **1.95**
Number of Taxa	≤7	8-10	11-14 **13**	15-17	≥18
Number of Individuals	≤79	129-80 **90**	212-130	349-213	≥350
Percent Dominant Taxa	≤61.6 **65.6**	61.5-43.9	43.8-31.2	31.1-22.2	≥ 22.1
EPT Index	≤2	3	4-5	6-7	≥8 **10**
EPT Count	≤19	20-42	43-91 **84**	92-194	≥195
EPT Count To Total Number of Individuals	≤0.13	0.14-0.29	0.30-0.46	0.47-0.68	≥0.69 **93.3%**

WATER BUDGET

Water enters Lake Greenwood from:

- direct precipitation to the lake
- sheet runoff from land immediately adjacent to the lake
- stream discharge
- groundwater

Water leaves the lake from:

- discharge from the outlet
- evaporation
- groundwater
- withdrawal for drinking water

There are no gages on the lake to measure water inputs or outputs so we must estimate this from other records. Direct precipitation to the lake can be calculated from mean annual precipitation and the lake's surface area. The mean annual precipitation for Martin County at Shoals, Indiana recorded in the period of 1951-74 was 43.2 inches (McElrath 1988).

Runoff from the lake's watershed can be estimated by applying runoff coefficients. A runoff coefficient refers to the percentage of precipitation that occurs as surface runoff, as opposed to that which soaks into the ground. Runoff coefficients may be estimated by comparing discharge from a nearby gaged watershed to the total amount of precipitation falling on that watershed. The nearest gaged watershed of similar size and land use to Lake Greenwood's watershed is a U.S.G.S. gaging station on the Lost River near Leipsic, Indiana in Orange County (Stewart et al., 2000). This watershed is 44 mi^2 in size but has more agricultural land that Lake Greenwood's watershed. We annualized the 20-year daily mean discharge for this watershed and divided it by the mean annual precipitation to derive a runoff coefficient of 0.345 is derived. This means that 34.5% of the rainfall falling on this watershed runs off on the land surface. We suspect that actual runoff may be slightly lower than this since Lake Greenwood's watershed is so heavily forested; however, the steep slopes and shallow soils enhance runoff. For comparison, the runoff coefficient for the heavily forested and hilly Bear Creek watershed in Brown County is 0.31 (Jones et al. 1984).

There exist no groundwater records for the lake so we must assume that groundwater inputs equal outputs. Because Lake Greenwood serves as the Crane drinking water supply, water is withdrawn to meet the demand for treated water. This withdrawal is estimated to be about 2.5 million ft^3 per month. Annual water budget input estimates for Lake Greenwood are summarized in Table 20.

Water flowing out of a lake (not including evaporation) is used in calculating the *hydraulic residence* time. When we divide this output water volume (12,674 ac-ft/yr) into the lake's volume (12,504 ac-ft), we derive a hydraulic residence time of 0.987 years. This means that it takes approximately one year for the lake's entire volume to be replaced by direct precipitation and surface runoff. While the hydraulic residence of many natural *drainage lakes* (those with surface inlets and outlets) in Indiana is about one year, reservoirs usually have shorter residence times due to their larger watersheds.

TABLE 20. Annual Water Budget Estimates for Lake Greenwood.

Category	**Operation**	**Result**
Direct Precipitation	Mean annual precip x lake surface area	(43.2 in/yr)(1 ft/12 in)(812 acres)(43,560 ft^2/acre) = **1.27 x 10^8 ft^3/yr**
Surface Runoff	Mean annual precipitation x watershed area x runoff coefficient	(43.2 in/yr)(1ft/12 in)(9472 ac)(43,560 ft^2/acre) (0.345) = **5.12 x 10^8 ft^3/yr**
Evaporation	Pan evap. x pan coefficient x lake surface area	(27.412 in/yr)(0.7)(812 ac)(43560 ft^2/acre) (1 ft/12 in) = **5.66 x 10^7 ft^3/yr**
Water Withdrawal		**3.03 x 10^7 ft^3/yr**
TOTAL INFLOW	Precipitation + runoff	**6.39 x 10^8 ft^3/yr (14,669 ac-ft/yr)**
TOTAL OUTFLOW (through outlet)	Inflow – evaporation - withdrawal	**5.52 x 10^8 ft^3/yr (12,674 ac-ft/yr)**

PHOSPHORUS BUDGET

Since phosphorus is the primary nutrient regulating the growth of algae in lakes, it is helpful to develop a phosphorus budget for lakes. However, since Lake Greenwood was nitrogen-limited at the time of our assessment, there would be interest in a nitrogen budget for the lake. Unfortunately, nitrogen budgets are very difficult to prepare and quite unreliable due to the dynamic and incalculable nature of atmospheric processes and nitrogen transformations within the lake.

The limited scope of this LARE study did not allow us to determine phosphorus inputs and outputs outright. Therefore, we have used a standard phosphorus model to estimate the phosphorus budget. Reckhow et al. (1980) compiled phosphorus loss rates from various land use activities as determined by a number of different studies, and calculated phosphorus export coefficients for each land use in the watershed (Table 1). We used upper mid-range estimates of these phosphorus export coefficient values due to the steep slopes in the watershed, which are expressed as kilograms of phosphorus lost per hectare of land per year, and multiplied them by the amounts of land in each of the land use categories to derive an estimate of annual phosphorus export (as kg/year) for each land use per watershed (Table 21).

TABLE 21. Phosphorus Export Coefficients (units are kg/hectare).

	Agriculture	Forest	Precipitation	Urban
High	3.0	0.45	0.6	5.0
Mid	0.40-1.70	0.15-0.30	0.20-0.50	0.80-3.0
Low	0.10	0.2	0.15	0.50

Source: Reckhow and Simpson (1980)

We estimated direct phosphorus input via precipitation by multiplying mean annual precipitation in Martin County (1.1 m/yr) times the surface area of Lake Greenwood (812 acres) times a typical phosphorus concentration in Indiana precipitation (0.035 mg/L). Since there are no septic systems in use along the lakeshore, there is no septic system loading of phosphorus. The results, shown in Table 22, yielded an estimated 2,192 kg of phosphorus exported from the watershed to the lake per year.

We can examine the relationships among the primary parameters that affect a lake's phosphorus concentration by using a phosphorus-loading model such as the widely used Vollenweider (1975) model. Vollenweider's empirical model says that the concentration of phosphorus ([P]) in a lake is proportional to the areal phosphorus loading (L, in g/m^2 lake area - year), and inversely proportional to the product of mean depth ($\bar{z}$) and hydraulic flushing rate (ρ) plus a constant (10), which helps account for phosphorus sedimentation within the lake:

$$[P] = \frac{L}{10 + \bar{z}\rho}$$

Table 22. Phosphorus Loading - Lake Response Model

LAKE:	Greenwood	DATE:	7/30/01
COUNTY:	Martin		
STATE:	Indiana		

INPUT DATA

		Unit
Area, Lake	812	acres
Volume, Lake	544674240	ft. cubed
Mean Depth	15.4	ft
Flushing Rate	1.01	vol/yr
Mean Annual Precipitation	1.10	m
[P] in precipitation	0.035	mg/l
[P] in epilimnion	0.058	mg/l
[P] in hypolimnion	0.073	mg/l
Volume of epilimnion	-	ac-ft
Volume of hypolimnion	-	ac-ft

Land Use (in watershed)	Area	--------	P-export Coefficient		P loading	
Row Crop	162.8	hectare	2.0	kg/ha-yr	325.60	kg/yr
Pasture	131.9	hectare	0.4	kg/ha-yr	52.76	kg/yr
Forest	2973.8	hectare	0.4	kg/ha-yr	1189.52	kg/yr
Urban	328.8	hectare	1.9	kg/ha-yr	624.72	kg/yr
Shrubland	0.0	hectare	0.2		0.00	kg/yr
Septic Systems	--------	--------	0.6	kg/ha-yr		
Total	3597.30				2192.60	

Other Data

Soil Retention coefficient	1.00	--------	**no operational septic systems
# Permanent Homes	3	homes	
Use of Permanent Homes	1.0	year	
# Seasonal Homes	0	homes	
Use of Seasonal Homes	0.00	year	
Avg. Persons Per Home	3	persons	

OUTPUT

P load from watershed	2192.60	kg/yr
P load from precipitation	126.52	kg/yr
P load from septic systems	0.00	kg/yr
Total External P load	2319.12	kg/yr
Areal P loading	0.706	g/m^2-yr
Predicted P from Vollenweider	0.048	mg/l
Back Calculated L total	0.958	g/m^2-yr
Estimation of L internal	0.252	g/m^2-yr
% of External Loading	73.7	%
% of Internal Loading	26.3	%

During our August 16, 2000 sampling of Lake Greenwood, the mean epilimnetic phosphorus concentration was 0.058 mg/L and the mean hypolimnetic phosphorus concentration was 0.073 mg/L. We'd normally calculate the volume-weighted mean phosphorus concentration but since the updated bathymetry isn't completed yet, we settled for the arithmetic mean of 0.065 mg/L.

Now it is useful to ask the question, "How much phosphorus loading from all sources is required to yield a mean phosphorus concentration of 0.065 mg/L in Lake Greenwood?" By plugging this mean concentration along with the mean depth and flushing rate into Vollenweider's phosphorus loading model and solving for L, we get an *areal phosphorus loading rate* (mass of phosphorus per unit area of lake) of 0.958 g/m^2-yr. This means that to get a mean phosphorus concentration of 0.065 mg/L in the lake, a total of 0.958 grams of phosphorus must be delivered to each square meter of lake surface area per year.

Total phosphorus loading (L_T) is composed of external phosphorus loading (L_E) and internal phosphorus loading (L_I). Since $L_T = 0.958$ g/m^2-yr and $L_E = 0.706$ g/m^2-yr (calculated from the watershed loading in Table 21), then internal phosphorus loading (L_I) equals 0.252 g/m^2-yr. Thus, internal loading accounts for 26% of total phosphorus loading to Lake Greenwood.

How reasonable is this conclusion that internal phosphorus loading accounts for 31% of total phosphorus loading to Lake Greenwood? Where does this internal phosphorus come from? There is no evidence that soluble phosphorus is being released from the sediments during periods of anoxia. This can be a major source of phosphorus in many productive lakes. A more likely source of this internal phosphorus could be the rooted macrophytes in the lake. These plants obtain the majority of their nutrients from the sediments. In essence, they 'pump' nutrients out of the sediments into their tissues. When the rooted plants die back in the fall, the nutrients contained within their tissues are released back into the water. In Monroe Reservoir, the annual fall senescence of Eurasian watermilfoil alone accounted for up to 24% of phosphorus and 2% of the nitrogen from all nonpoint sources (Landers and Frey 1980). This release resulted in a massive fall algal bloom in the reservoir. If we consider all the rooted plant species in Lake Greenwood, it is likely that they contribute a significant amount of phosphorus to the lake at the time of fall dieback.

The significance of this areal loading rate is better illustrated in Figure 22 in which areal phosphorus loading is plotted against the product of mean depth and flushing rate. Overlain on this graph is a curve, based on Vollenweider's model, which represent an acceptable loading rate that yields a phosphorus concentration in lake water of 30 μg/L (0.03 mg/L). A phosphorus concentration of 0.03 mg/L is one that is near the median phosphorus concentration for mesotrophic lakes according to Vollenweider (Table 6). Lake Greenwood's current loading rate of 0.951 g/m^2-yr falls just into the excessive loading portion of the graph.

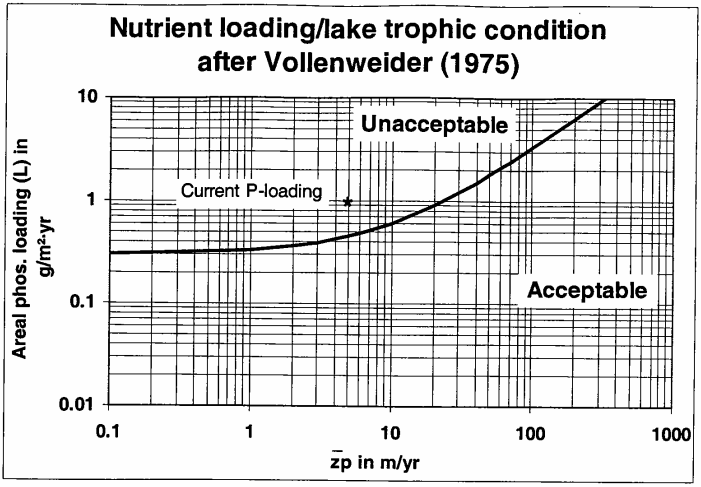


Figure 22. Evaluation of phosphorus loading and trophic state in Lake Greenwood.

This figure can also be used to evaluate management needs. For example, areal phosphorus loading would have to be reduced to 0.44 g/m^2-yr to yield a mean lake water concentration of 30 µg/L. This represents a reduction in phosphorus mass loading to the lake of 1,445 kg/yr, a 54% reduction in the current total annual phosphorus loading.

MANAGEMENT ALTERNATIVES

Problem Identification

Lake Greenwood is a relatively clear reservoir with very good water quality when compared to other Indiana lakes. However, symptoms of eutrophication are present despite the low Indiana TSI score. These symptoms include: somewhat high phosphorus concentrations, an extensive rooted plant community, and declining dissolved oxygen concentrations in the hypolimnion.

There is abundant light for algae and rooted macrophyte production in Lake Greenwood. Phosphorus concentrations are sufficient to promote eutrophic conditions. However, N : P ratios are low enough (3 : 1) to suggest nitrogen limitation. This low ratio is not caused, as usually seen, by extremely excessive phosphorus concentrations (Aldridge 1993) but because nitrogen concentrations themselves are low. Therefore, we must conclude that nitrogen limitation inhibits algal productivity in Lake Greenwood.

Rooted aquatic plants, on the other hand, get most of their nutrients from the sediments and the rooted plant community is very robust, due to extensive shallows and suitable substrates. While a healthy, diverse rooted plant community is desirable in lakes, the plant community within Lake Greenwood is dominated by Eurasian watermilfoil, an aggressive non-native species. Eurasian watermilfoil has become dominant only within the past five years. Each fall, when these plants die back, they settle onto the bottom sediments where the decomposing organisms feed on them throughout the summer. Our sediment analyses showed that the organic matter content of the sediments is higher than that of most reservoirs. This suggests that excess organic matter from decaying plants and from allochthonous sources is starting to build up in the sediments.

Biochemical oxygen demand (BOD) from decaying algae, plants and other organic matter consumes oxygen and this process results in oxygen depletion in water deeper than 7 meters in Lake Greenwood. This reduces available habitat for fish and other aquatic organisms. A further consequence of low oxygen levels is the creation of chemically reducing conditions. With reducing conditions inorganic phosphorus, otherwise tied up with iron and other cations in the sediments, can be released back into the water. Ammonia, the primary by-product of bacterial decomposition of organic matter, can also build up in the anoxic hypolimnion of a productive lake. Currently, there is no evidence of either internal phosphorus release or ammonia accumulation in the lake.

Management Needs

The problems identified in our analysis of Lake Greenwood that require management include:

1. Extensive beds of Eurasian watermilfoil
2. Oxygen depletion in deeper waters (hypolimnion)
3. Excessive phosphorus loading
4. Lakeshore destabilization
5. Watershed erosion.

There are several in-lake and watershed management alternatives available to address these problems.

Aquatic Plant Management

A comprehensive aquatic plant management program can address the first three of these problems. A reduced aquatic plant population in Lake Greenwood will help reduce hypolimnetic oxygen depletion and internal phosphorus loading.

All lakes need a diverse aquatic plant population to provide all the benefits that such plant communities provide – fish and aquatic insect habitat, sediment stabilization, wave dampening, oxygen generation, etc. (Table 10). However, when aquatic plants become too dense or lack diversity, they may become a problem. This is what has happened in Lake Greenwood. The major problems with the aquatic plant community that can be addressed in a management program are:

1. Annual aquatic plant die-off contributes excessive organic material and nutrients to the lake sediments that results in oxygen depletion and increased phosphorus.

2. Plants may be too dense for optimal fish production because they shelter prey species from predators.

3. Non-native plant species dominate native species.

4. Dense plant beds interfere with human use of shallow areas of the lake.

Let us state clearly that aquatic plant management does not mean aquatic plant eradication. We recommend selective control only. Areas dominated by non-native plants should be targeted for more thorough control. In other areas, selective plant control through dense aquatic plant beds can create 'cruising lanes' for fish. These lanes allow predators (for example, largemouth bass) to get access to small, slow-growing prey species (bluegill, redear, etc.). This can increase the growth rates and size of predators and prey alike.

Mechanical Harvesting. There are several options for aquatic plant management. Mechanical harvesting can be applied where needed, can create cruising lanes for predator fish, and removes the cut plant material from the lake. This way, the plants do not contribute to the BOD problems cited previously.

Mechanical harvesting can manage the growth of aquatic macrophytes and give the lake user immediate access to areas and activities that had been affected by excessive macrophyte growth. Plants harvested several times during the growing season, especially late in the season, often grow more slowly the following year (Cooke et al., 1993). Many harvested plants, especially milfoil, can re-root or reproduce vegetatively from the cut pieces if left in the water. Long-term control of Eurasian watermilfoil populations through mechanical harvesting alone may be difficult. In a recent 9-year study of nine lakes in southeastern Wisconsin, Helsel et al. (1999) concluded that typical mechanical harvesting and chemical treatment activities were unlikely to reduce Eurasian watermilfoil more rapidly than if no management occurs.

Although many claim that harvesting is environmentally superior to herbicide use, most neglect to consider that harvesting removes large numbers of macroinvertebrates, semi-aquatic vertebrates, forage fishes, young-of-the-year fishes, and even adult gamefishes (Engel 1990).

Mechanical harvesting costs vary according to capital cost and capacity of the harvester, amortization rate, amount of time required to unload harvested material, size of lake, and other factors. Depending upon the specific situation, harvesting costs can range from $600 to $2,000 per hectare (Cooke et al. 1993). Estimated costs of the mechanical harvesting program at Lake Lemon averaged $659 per hectare (Zogorski et al., 1986).

Lake Level Drawdown. Lake level drawdown can be used as a macrophyte control technique or as an aid to other lake improvement techniques. This technique requires the ability to discharge water from a lake through an outlet structure or dam. Drawdown can be used to provide access to dams, docks, and shoreline stabilizing structures for repairs; to allow dredging with conventional earthmoving equipment; and to facilitate placement of sediment covers.

As a macrophyte control technique, drawdown is recommended in situations where prolonged (one month or more) dewatering of sediments is possible under conditions of severe heat or cold and where susceptible species are the major nuisances. *Myriophyllum spicatum* (Eurasian watermilfoil) control for example, apparently requires three weeks or longer of dewatering prior to a one-month freezing period (Cooke 1980). Cooke (1980b) classifies 63 macrophyte species as decreased, increased, or unchanged after drawdown. One must note the presence of resistant as well as susceptible species, since resistant species can experience a growth surge after a successful drawdown operation. Native species in Lake Greenwood such as fragrant water lily, spatterdock, and chara also decrease with winter drawdown. Other species present in Lake Greenwood are known to increase (slender naiad and cattail) or have no change (vallisneria) with drawdown.

Macrophyte control during drawdown is achieved by destroying seeds and vegetative reproductive structures (e.g., tubers, rhizomes) via exposure to drying or freezing conditions. To do so, complete dewatering and consolidation of sediments is necessary. Dewatering may not be possible in seepage lakes.

There are a number of other benefits to lakes and reservoirs from drawdown. Game fishing often improves after a drawdown because it forces smaller fish out of the shallow areas and concentrates them with the predators (bass, walleye, pike). This decreases the probability of stunted fish and increases the winter growth of the larger game fish. Drawdown has also been used to consolidate loose, flocculent sediments that can be a source of turbidity in lakes. Dewatering compacts the sediments and they remain compacted after reflooding (see Born et al. 1973 and Fox et al. 1977).

A final consideration in implementation of lake level drawdown is season -- winter or summer are usually chosen because they are most severe. According to Cooke (1980b), it is not clear whether drawdown and exposure of lake sediments to dry, hot conditions is more effective than exposure to dry, freezing conditions. One factor to consider is which season is most rigorous. Advantages of winter drawdown include less interference with recreation, ease of spring versus autumn refill, and no invasion of terrestrial plants. Sediment dewatering is easier in summer.

In Murphy Flowage, a 73 ha (180 acre) reservoir in Wisconsin, a five foot drawdown from mid-October to March greatly reduced the presence of aquatic macrophytes the following growing season. *Myriophyllum* spp. was reduced from 8 ha to <1 ha coverage, *Nuphar* spp. was reduced from 17 ha to 5 ha, and *Potamogeton* spp. was reduced from 46 ha to 3 ha (Beard 1973).

In lakes and reservoirs already having an operational outlet structure to facilitate the water release, lake level drawdown is an attractive lake management technique due to its low cost and because introduction of chemicals and machinery is not necessary. A new deep-water intake at Lake Greenwood for drinking water treatment would likely allow drawdown without affecting water treatment.

Biological Controls. The most promising of biological controls that could be considered in Lake Greenwood is the milfoil weevil (*Euhrychiopsis lecontei*). Laboratory, mesocosm, and field research have been vigorously pursued on this organism. *Euhrychiopsis lecontei* looks promising in that it is capable of cutting off the flow of carbohydrates to root crowns, reducing the plant's ability to store carbohydrates for over wintering and reducing the buoyancy of the canopy (Madson 2000). However, an effective strategy for large-scale applications using these naturalized insects at an operational level has yet to be verified. Field trials on three Indiana lakes are currently being conducted and it may be best to wait for the independent monitoring results before considering its application on Lake Greenwood. A nine-year study of nine southeastern Wisconsin lakes suggested that weevil activity might have contributed to Eurasian watermilfoil declines in the lakes (Helsel et al. 1999).

Chemical Controls. Because Lake Greenwood is a drinking water supply, the use of aquatic herbicides is severely restricted by the U.S. Environmental Protection Agency. Fluridone, marketed under the trade name SONAR, is the only aquatic herbicide for macrophytes approved for use in water supplies according to Mark Mongin (pers. com. 2001). Fluridone is a nonselective systemic aquatic herbicide. It requires very long exposure times but may be effective at very low concentrations. For example, a concentration in the treated water of 20 ppb is effective on Eurasian watermilfoil. This is well below the maximum label rate for use in potable water supplies (150 ppb). Fluridone appears to work best where the entire water body can be managed, but not in spot treatments or high water exchange areas (Madson 2000).

Fluridone is very expensive (>$1,000/gallon) and it should be applied only by highly experienced applicators. Application requires a bioassay of plants to determine the effective concentration and careful monitoring of the concentration in the water (Mongin 2001).

Preventive Measures. Although milfoil is thought to 'hitchhike' on the feet and feathers of waterfowl as they move from infected to uninfected waters, the greatest threat of spreading this invasive plant is humans. Plant fragments snag on boat motors and trailers as boats are hauled out of lakes (Figure 23). Milfoil, for example, can survive for up to a week in this state – then it can infect a milfoil-free lake when the boat and trailer are launched next. It is important to educate boaters to clean their boats and trailers of all plant fragments each time they retrieve them from a lake.

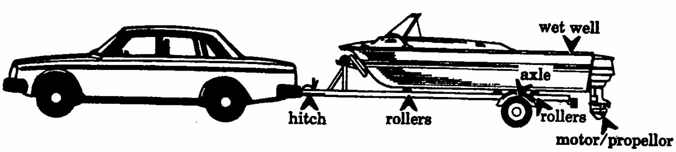


Figure 23. Locations where aquatic macrophytes are often found.

Lakeshore Stabilization

We have identified unstable and eroded shoreline areas around the lake (Figures 18-20). There are a variety of lakeshore protection practices designed to stabilize and protect these areas against scour and erosion from forces such as wave action, ice action, seepage, and runoff from upland areas. Shoreline stabilization methods fall into two broad categories: nonstructural (e.g., vegetation) and structural (flexible structures such as rip-rap and rigid structures like seawalls) (McComas 1986).

Vegetative Stabilization. Vegetation effectively controls runoff erosion on slopes or banks leading down to the water's edge; however, vegetation is generally ineffective against direct wave action or seepage-caused bank slumping. The type of vegetation to establish depends on the steepness of the slope. If the slope angle is steeper than 1:1 (i.e., 1 foot horizontal for every 1 foot vertical), the soil is probably unstable and the possibility of establishing protective vegetative cover is slight (McComas 1986). Steep slopes should be re-graded to a 2:1 slope or flatter (SCS 1989). All materials excavated from sloped banks may be placed on the bank, leveled, and seeded to prevent erosion during high water or hauled to other areas for use. Do not place excavated material into the lake or stream, or form barriers that interfere with runoff entering natural channels.

On long, steep slopes leading down to the water's edge where regrading to a gentler slope is too impractical, consider slope modifications which will allow vegetation to become established (Figure 24). Slope terracing provides horizontal steps in which to plant vegetation. Contour wattles are bundles of live willow cuttings anchored into the bluff face with either construction or live willow cuttings (Michigan Sea Grant Program 1988). The bundles trap surface runoff and soil particles and lets vegetation become established.

Once an appropriate slope is created, seed or plant the bare soil immediately. Use erosion control mats of nylon mesh or wood excelsior on top of the soil to assist in seed germination, seedling protection, and erosion control. Time your work to coincide with optimal planting times. Grasses can be planted in the spring or fall while woody plants should be planted when they are dormant. A protective grass cover can be established within one year. Slopes should be 3:1 or flatter to facilitate mowing, although unmowed grass maximizes water retention and solids trapping. Herbaceous ground covers, shrubs and trees may take several years to become established. Ground covers are useful when mowing isn't desired. When using trees or shrubs to stabilize banks, plant grasses initially until the woody vegetation becomes established. A guideline for vegetative covers is presented in Table 23.

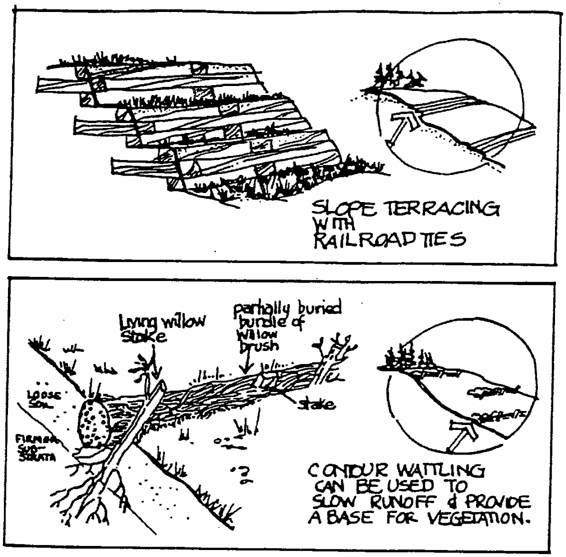


Figure 24. Modifications for long slopes. Source: Michigan Sea Grant Program (1988)

Structural Methods. Riprap is a flexible structure constructed of stone and gravel which is designed to protect steeper (slope > 1:1) shorelines from wave action, ice action and slumping due to seepage. The riprap is flexible in that it will give slightly under certain conditions. This improves its ability to dissipate wave energy. Riprapping involves more than simply dumping rocks on the shoreline. Filter fabric or graded stone must be used on the soil base to prevent soil from moving through the stone and undercutting it. The toe (bottom) of the riprap must be protected by burying it at least three feet below the sediment surface (Figure 25). The size of the largest stones used depends on the design wave height. Traditional riprap may be modified to present a more natural look by integrating live cuttings or tamping live stakes of species such as black willows in between the rock layers (Figure 26). The roots improve drainage and create a mat that binds and reinforces the soil, preventing washouts and loss of fines between and below the rocks (Reichert 1995). See SCS Standards and Specifications 580 entitled, "Streambank and Shoreline Protection" (SCS 1989) or your county SCS agent for more information.

TABLE 23. Vegetation for Lakeshore and Streambank Slopes.

Vegetation	>3:1 Slope	> 1:1 Slope
Grasses	Kentucky bluegrass[a]	red fescue[a]
		switchgrass
		big bluestem
		little bluestem
Ground Covers	(same as >1:1 slope)	goutweed
		bearberry
		crown vetch[a]
		memorial rose
		creeping juniper
		purple wintercreeper
Shrubs	(same as >1:1 slope)	red chokecherry
		gray dogwood
		sumac
		common juniper
		common witch hazel
		border privet
		snowberry
		tatarian honeysuckle[a]
Trees	(same as >1:1 slope)	red maple
		silver maple
		paper birch[a]
		white ash
		white pine
		black cherry

Adapted from: McComas (1986)
[a]non-native species that the Indiana DNR considers potentially invasive.

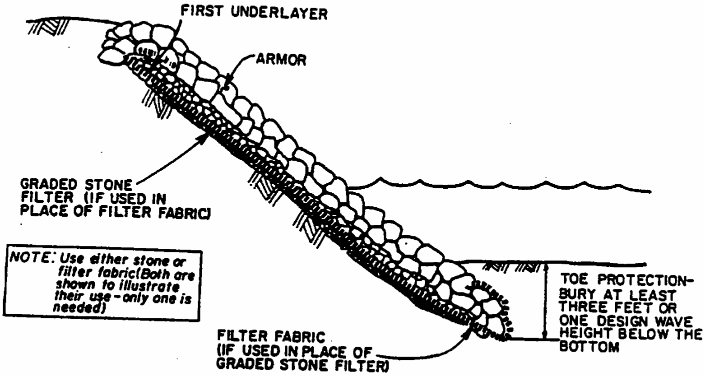


Figure 25. Cross section of a properly riprapped shore line. Source: McComas (1986)

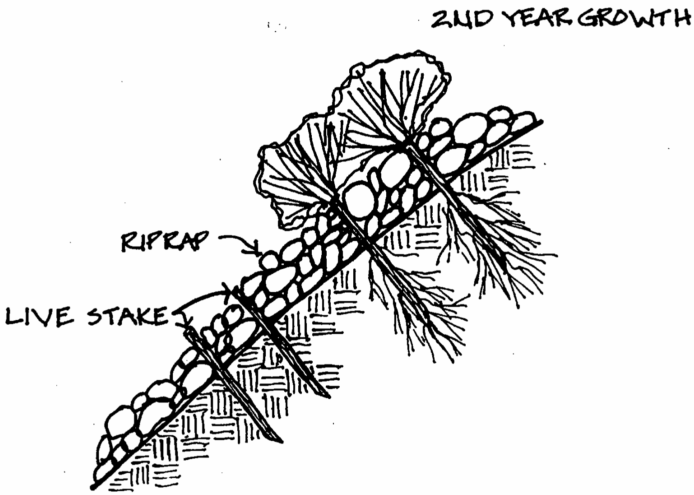


Figure 26. Vegetated riprap. Source: Reichert (1995).

Other bioengineering components that integrate vegetative and structural components include live cribwalls (Figure 27) and vegetated gabions (Figure 28). In a live cribwall, a log or timber crib is combined with live branches of willows, alders, dogwood or other deeply rooted woody species. Plant stakes can be cut during dormant periods (spring, winter or fall) from available stands on site but must be used the same day as cut. Live cribwalls are effective at the base of slopes where a low wall, not higher than 6 feet, is required (Reichert 1995).

Vegetated gabions combine the same woody species as above with gabions (wire mesh rectangular boxes filled with stone and used as a retaining wall). The gabions may be stacked or terraced.

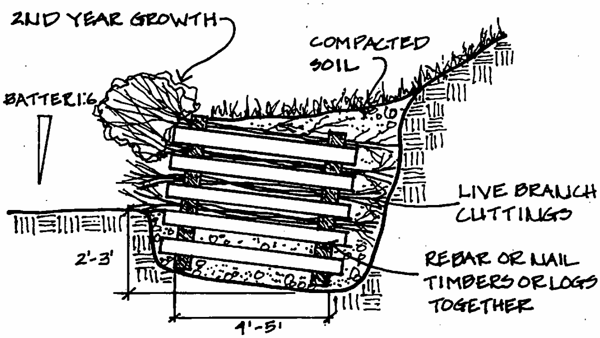


Figure 27. Live cribwall. Source: Reichert (1995).

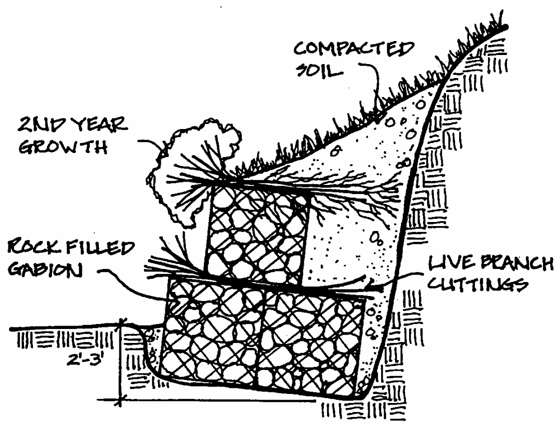


Figure 28. Vegetated gabion. Source: Reichert (1995).

Seawalls, bulkheads, and retaining walls are rigid structures used where steep banks prohibit the sloping forms of protection. Seawalls primarily prevent land masses from sliding from the shore into the water and secondarily prevent wave action from damaging the shoreline. Seawalls do not dissipate wave energy but rather, redirect the wave energy away from the shore. This often erodes the shoreline at the base of the wall and may affect the slope of the lake bottom some distance from shore. The cumulative effect of too many seawalls around a lake can be devastating to aquatic species.

The placement of riprap and seawalls is best left to the professional. *The use of structural controls requires a permit from the Indiana Department of Natural Resources and may require a 404 Permit from the U.S. Army Corps of Engineers. These agencies must be contacted before any material is placed or deposited in a stream channel or on a lake bed.*

Drainageway Management

The extensive use of paved drainageways (road ditches) along Crane roads encourages erosion in several ways: 1) runoff water achieves very high velocities in the paved drainageway and it is the high velocity that increases soil erosion at the outlet of the drainageway and downstream, and 2) there is no chance for infiltration that would reduce the runoff volume. Modern stormwater management focuses on practices that reduce water velocities and retain some water on site. Replacing the paved ditches with grassed waterways or stone-lined ditches will reduce the velocity of water carried in the ditch and will allow infiltration to reduce the runoff volume, sediments and associated nutrients. BMPs discussed above for lake shorelines may also be used to stabilize banks along drainageways and streams.

Grassed waterways (grass lined ditches) are natural or constructed waterways or outlets, shaped or graded, and established in suitable vegetation. They provide an opportunity for sediments and other pollutants to be removed from runoff water before it enters surface waters by controlling, slowing and filtering the water through vegetation or structures (Reichert 1995). They are probably the least expensive but most effective means of conveying water across gently-sloping (0 – 5% slope) land. The ditch banks should have a maximum slope 2 horizontal : 1 vertical ratio. The ditch bottom should be flat (parabolic-shaped preferred) and at least 2 feet wide to help slow and disperse water (Figure 29). Generally, the efficiency of pollutant removal by grassed waterways is about 30% but sediment removal efficiencies of 60-80 percent have been reported in properly designed and maintained waterways. Removal efficiencies are maximized by low channel slopes and slow water velocities. Table 24 gives basic design criteria for grassed waterways.

Stone-lined ditches are another alternative to paved ditches where channel slopes are too steep for grass-lined ditches. For channel slopes of 5 – 10%, a 7.5-inch lining of 2-6 inch diameter rock is recommended (Figure 30). For slopes steeper than 10%, a 12-inch lining of 3-12 inch diameter rock is needed (Reichert 1995).

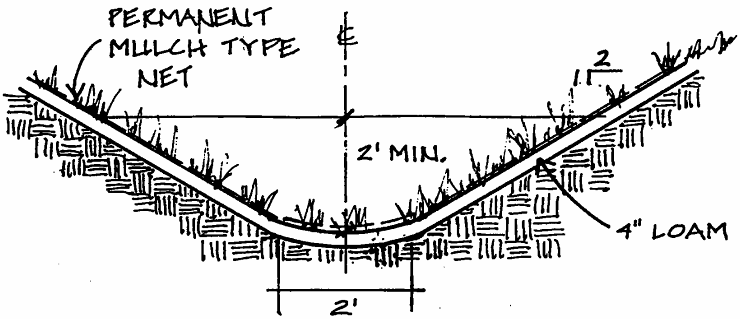


Figure 29. Grass-lined ditch detail. Source: Reichert (1995).

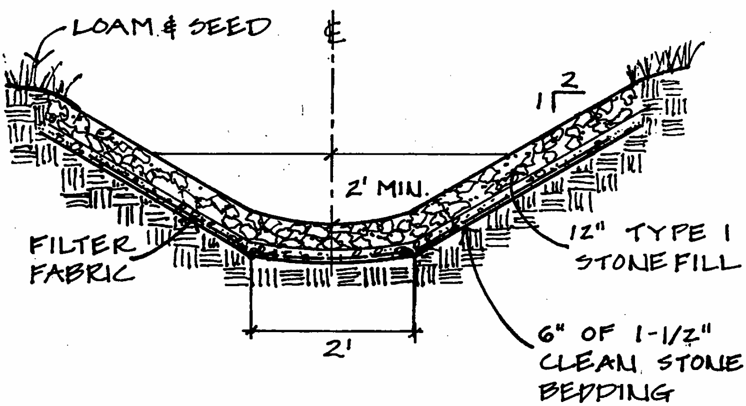


Figure 30. Stone-lined ditch detail. Source: Reichert (1995).

In long drainageways, drop structures should be used to slow down water velocity. Drop structures are low-head structures placed across a drainageway (Figure 31). Reducing water velocity not only decreases the erosive potential of the flowing water, but also allows sediment particles (and attached nutrients) to settle out. In addition, woody debris and trash may also be trapped before reaching culverts and becoming lodged inside. The velocity control may be sheet piling, wood timbers, or rock. In addition, they temporarily store a small amount of water that reduces the peak runoff volume. These have been effectively used in other LARE projects (for example, Lawrence Pontius Ditch – Figure 32).

Table 24. **Maximum Permissible Design Velocities for Grassed Waterways.**

Cover	**Range of Channel Gradient (%)**	**Permissible Velocity (m/sec)**
Vegetative 1. Tufcote, Midland and Coastal Bermuda Grass	0 - 5.0 5.1 - 10.0 Over 10	1.8 1.5 1.2
2. Reed canary grass, Kentucky 31 tall fescue, Kentucky bluegrass	0 - 5.0 5.1 - 10.0 Over 10	1.5 1.2 0.9
3. Red fescue	0 - 5.0	0.75
4. Annuals[a] - ryegrass	0 - 5.0	0.75
Unlined Channels[b] 5. Fine gravel		0.75 - 1.5
6. Coarse gravel		1.2 - 1.8

[a]Annuals-use only as temporary protection until permanent vegetation is established.
[b]Lower velocity is recommended for clean water; higher is allowed for silty water.
Source: Novotny and Olem (1994)

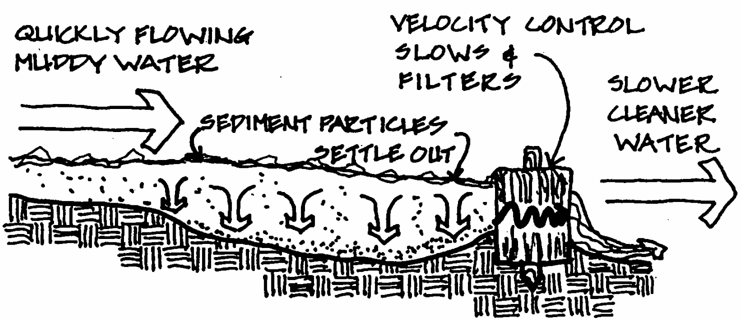


Figure 31. Typical velocity control structure. Source: Reichert (1995).

Figure 31. Sheet piling velocity control structure on Lawrence Pontius Ditch, Marshall County.

Culverts. Existing erosion damage around and below affected culverts should be repaired to prevent additional damage. In time, erosion at a culvert outlet will work its way upgradient to destabilize the entire culvert. To prevent this, eroded culvert outlets must be protected with rock or concrete reinforcement. Many of the culverts surrounding Lake Greenwood were protected with concrete headers and sills (Figure 32). Headwalls help prevent the undercutting and back cutting problems. Unprotected culverts (see Figure 13) require the stabilization afforded by headwalls. In addition, drainageways below culverts can be protected with stone lining as discussed above to prevent downstream erosion. A plunge pool or basin immediately below culvert outlets will help trap additional sediments. The total cost of materials, labor and equipment to replace a culvert, install a concrete header, and stabilize the banks with riprap can cost as much as $10,000 but can save $25,000 in maintenance over 35 years (Vermont Local Roads 1997).

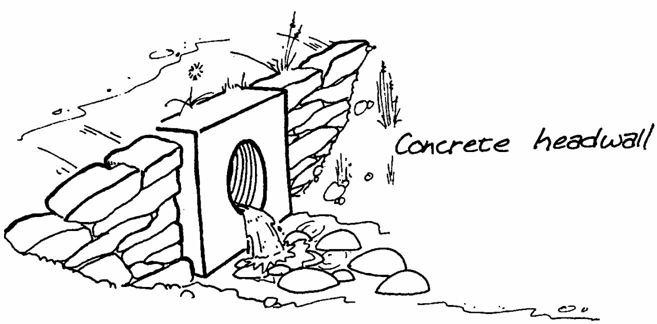


Figure 32. Culvert outlet protected with a concrete header. Source: Lambert (1997).

Constructed Wetlands. There is very little wetland acreage within Lake Greenwood's watershed (see Figure 7). Wetlands are emerging as a low-cost, efficient treatment system for a wide variety of wastewaters, including: stormwater, acid mine drainage, and sanitary wastes. Treatment efficiencies vary with design, vegetation used, soil conditions, and loading rates but removal rates of 95% for sediment, 90% for total phosphorus, and 75% for total nitrogen are reported in the literature (Livingston 1989; Kadlec and Knight 1996).

There are several important design considerations to consider for enhancing the sediment and nutrient removal efficiencies of constructed or enhanced wetlands. These include:

1. Sizing the wetland to the drainage area.
2. Reducing water velocities through the system.
3. Maintaining optimal water levels.
4. Pre-treating to remove sediments.

Opportunities exist for the construction of treatment wetlands on and along the major tributaries to Lake Greenwood. The steep slopes and confined valleys of many stream reaches in the watershed would make it difficult to site wetlands. However, lowlands bordering our stream sampling sites (see Figure 14) would be natural possibilities with the proper engineering design.

Forestry Management

Approximately one million dollars worth of timber is harvested from the Crane site each year. Logging on the steep slopes of the site can destabilize soils, increase runoff velocities, and increase the transport of organic material (and its associated nitrogen and phosphorus) to downgradient areas. While current forestry practices at Crane follow all state BMP guidelines, extra care is warranted on the steep slopes and shallow soils within Lake Greenwood's watershed.

1. Planning - The landowner and logger should mutually spend time planning and laying out skid and access roads and landings to prevent potential problems. This includes fitting the roads to the lay of the land and keeping grades low. Well-planned and properly located roads can be great assets to the logged property. Permanent roads permit access for fire protection, firewood cutting, future timber management, and harvesting.

2. Stream Buffers - Roads and landings should be sited at least 100 feet from streams and ponds. Equipment should be kept out of streams. A filter strip of vegetation should be left along the stream.

3. Stream Crossings - When a stream must be crossed, a culvert or bridge should be used. The crossing should be at a right angle to the stream, and the approaching reads should not drain water into the stream.

4. Drainage - The logger should use ditches, culverts, dips, and grade breaks, and log in favorable weather when possible. Drainage structures need to be maintained during operation to

keep them working. To prevent water from washing down long stretches of road or standing in landings or dips, the logger should inspect ditches, culverts, etc., periodically to make sure they are effective. If muddy water is noticed entering a stream, or if there is a possibility of this, steps need to be taken to correct the problem.

5. Site Closure - Retire logging roads as soon as they are not needed. Do not wait until the whole job is completed. For example:

a. Smooth and grade landings and main haul road for drainage, utility and appearance.
b. Clean ditches and culverts that are permanent.
c. Pull out temporary culverts and bridges and regrade cross-ditch. All natural drainages should flow across, not down, the road.
d. Plant a cover crop on all exposed soil using lime, fertilizer, mulch and seed such as Kentucky 31 fescue (grass) as needed.
e. Gate road or use a deep trench to eliminate vehicle access.
f. Plan for future maintenance - the cleaning or repairing of water control structures.
g. Install water bars or water-breaks at recommended intervals. Rocks, brush and logging debris can often be used as water retardants on skid trails.

Agricultural Management

Agricultural lands are located at the far reaches of Lake Greenwood's watershed. These lands are also primarily used for pasture. Given this, we recommend no specific agricultural BMPs.

Monitoring

It would be wise to monitor soluble and total phosphorus in Lake Greenwood over the fall rooted plant dieback period to determine the extent of phosphorus inputs from senescing plants. This would help confirm whether this is an important annual source of nutrients to Lake Greenwood.

Regular monitoring of causal variables (e.g., phosphorus, nitrogen) and indicator response variables (e.g., Secchi disk transparency, chlorophyll *a*) is essential to understanding seasonal and long-term water quality trends. By understanding these patterns, the lake manager is in a better position to identify significant changes and to take precautionary measures before water quality conditions degrade.

RECOMMENDATIONS

This study identified a number of management needs at Lake Greenwood and its watershed. These were discussed in detail in the preceding section. The recommended management plan for Lake Greenwood includes a combination of watershed management practices and in-lake controls to manage the problems identified. For the most part, this plan includes technically feasible techniques that have been proven effective in numerous cases on other lakes.

Our goal with this plan is to maintain the current water quality of the lake, which at present is very acceptable. However, maintenance of the current conditions is not trivial nor will it be easy. Threats to Lake Greenwood abound:

- Expansion of Crane facilities and the resulting increase in impervious surfaces will cause additional stormwater runoff stress on the surface drainage infrastructure,
- The current surface water drainage infrastructure is deteriorated to the point where significant financial resources are necessary to maintain it,
- Disturbance of the forest cover on the watershed's steep slopes, be it facility construction or timber harvesting, risks significant soil erosion and increased runoff,
- Eurasian watermilfoil, a non-native aggressive aquatic plant already in abundance, has the potential to displace native macrophytes, leading to an aquatic plant community monoculture with little habitat value,
- We can only speculate what might happen in the unlikely event that ordinance or other materials stored in bunkers or processed within the lake's watershed were to enter the lake through runoff or leaching into the groundwater.

Comprehensive lake and watershed management requires more than 'putting out fires'. It requires broad vision, purposeful planning, and integration of resources. A big advantage in managing Lake Greenwood is the fact that nearly the entire watershed is controlled by one entity – NSWC Crane. Thus, working with recalcitrant landowners and municipalities, common in most other lake management programs, is not an issue here.

The following management efforts are recommended. The first listed is most pressing and will have the greatest effect on insuring the long-term quality of Lake Greenwood. However, all of the recommendations must be implemented as part of a comprehensive management program for the lake.

1. **Stabilize eroded culverts and drainageways**. There are many thousands of culverts on the Crane property. These are part of an aging stormwater management infrastructure that is needed to handle surface runoff from the steep land slopes. The problem is especially severe along the northern side of Lake Greenwood along Road 331. Specifically, the worst drainage problems we saw were on the steep hill immediately east of the gun range on Road 331. Activities should:

   - Repair/replace damaged culvert outlets with concrete or rock headers
   - Stabilize channels below culvert outlets with rock lining
   - Replace concrete-lined roadside ditches with rock-lined ditches containing velocity control structures

2. **Minimize all future disturbances to the stabilizing vegetative cover on steep slopes.** When disturbance is necessary, BMPs should be used to their fullest extent.

3. **Utilize wetland treatment.** Where feasible sites exist, constructed wetland treatment systems can be effective at reducing the delivery of runoff, sediments, and nutrients to Lake Greenwood. Possible locations for developing wetland treatment systems include our sampling sites on Little First Creek at Road 331 and on First Creek at Road 290.

4. **Stabilize eroded shoreline areas**. Vegetation or bioengineering methods that incorporate vegetation create a more natural look and a longer lasting repair. Bare shoreline banks greater than 6 feet high, such as those to the west of the marina, should be stabilized first.

5. **Insure that BMPs are fully used with all forestry practices.** Logging is an important forest management activity at Crane. Logging on steep slopes presents additional concerns from flat land logging. Only loggers with demonstrated experience should be contracted and full use of forestry BMPs must occur. The goal of any logging within the Lake Greenwood watershed must be <u>no net increase in runoff or soil loss</u>. Meeting this goal will require BMPs more stringent than those required by the State in general.

6. **Milfoil control.** Consider control of Eurasian watermilfoil if monitoring shows that it interferes with native aquatic biota or recreation.

   - **Herbicides.** The large size of Lake Greenwood and the long wind fetch cause significant water circulation that would likely preclude small-area treatments with fluridone, unless a curtain barrier is used to isolate the treatment area to prevent mixing and maintain the effective concentration. Given this, herbicide use would likely require a whole-lake treatment of fluridone – an extremely expensive proposition.
   - **Mechanical harvesting.** Spot harvesting with a mechanical harvester would be effective in opening up cruising lanes for boaters and fish predators should the coverage of milfoil become extensive. However, this will likely be a cosmetic treatment only unless areas are harvested 3 or more times per year.
   - **Drawdown.** Drawdown is recommended if the lake level can be lowered in the fall, however, this technique depends on a cold, dry winter.
   - **Milfoil weevil.** The milfoil weevil shows promise and may be 'right' for Lake Greenwood, however, definitive trial results must demonstrate the effectiveness and proper use of this technique first.

7. **Boater Education.** Educate boaters about milfoil and how they can help prevent its spread.
   - The brochure prepared as a task of this study will help implement this.
   - Signs should be erected at the boat launches to further reinforce the message.
   - Marker buoys are needed to warn boaters of shallow shoals containing milfoil where boats can fragment and spread this invasive plant.

8. **Monitoring.** There is currently no long-term monitoring of Lake Greenwood, save for periodic fisheries surveys. At minimum, Lake Greenwood should be enrolled in the Indiana Department of Environmental Management's Volunteer Lake Monitoring Program.

REFERENCES CITED

Aldridge, F.J., C.L. Schelske and H.J Carrick. 1993. Nutrient limitation in a hypereutrophic Florida lake. Arch. Hydrobiol. 127(1): 21-37.

Allen, John. 2000. Personal Communication.

Andrews, Steve. 2000. Personal Communication.

APHA et al. 1995. Standard Methods for the Examination of Water and Wastewater, 19th edition. American Public Health Association, Washington, D.C.

Barbour et al. 1999. Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers: Periphyton, Benthic Macroinvertebrates, and Fish. 2nd Edition. USEPA, Office of Water. Washington, D.C. EPA 841-B99-002.

Beard, T.D. 1973. Overwinter Drawdown - Impact on the Aquatic Vegetation in Murphy Flowage, Wisconsin. Tech. Bull. No. 61. Wisconsin Dept. Nat. Resour., Madison, WI.

Borman, S., R. Korth and J. Temte. 1997. Through the Looking Glass – A Field Guide to Aquatic Plants. Wisconsin Lakes Partnership, University of Wisconsin-Extension, Stevens Point, Wisconsin.

Born, S.M. T.L. Wirth, J.O. Peterson, J.P. Wall and D.A. Stephenson. 1973. Dilutional Pumping at Snake Lake, Wisconsin. Wisconsin Department of Natural Resources Technical Bulletin No. 66, Madison, Wisconsin.

Bowman, M.F. and R.C. Bailey. 1997. Does taxonomic resolution affect the multivariate description of the structure of freshwater benthic macroinvertebrate communities? Can. J. of Fisheries and Aquatic Sciences. 54:1802-1807.

Clark, G.D. (ed). 1980. The Indiana Water Resource – Availability, Uses, and Needs. Governor's Water Resource Study Commission, Indianapolis, Indiana.

Clark, G.M., D.K. Mueller and M.A. Mast. 2000. Nutrient concentrations and yields in undeveloped stream basins of the United States. J. Am. Water Resour. Assoc., 36(4): 849-860.

CLP. 1996. Lake Water Quality Assessment Report – Lake Greenwood. Indiana Clean Lakes Program, School of Public and Environmental Affairs, Indiana University, Bloomington.

Cooke, G.D. 1980. Lake level drawdown as a macrophyte control technique. Water Resources Bulletin, 16:317-322.

Cooke, G.D., E.B. Welch, S.A. Peterson and P.R. Newroth. 1993. Restoration and Management of Lakes and Reservoirs, Second Edition. Lewis Publishers, Boca Raton.

Crane. 2000. Lake Greenwood Marina and Outdoor Recreation Area (brochure). Quality of Life Department, NSWC Crane.

Crane. 1996. Lake Greenwood Visitor's Handout. Naval Surface Warfare Center, Crane, Indiana.

Crane. 1995. Natural Resources Guide – Informal Information for Our Visitors Enjoyment (pamphlet). Naval Surface Warfare Center, Crane, Indiana.

DNR. 1993. Indiana Lakes Guide. Department of Natural Resources, Division of Water, Indianapolis, Indiana.

Echelberger, W.E., W.W. Jones and others. 1984. Cedar Lake Restoration Feasibility Study. ESAC-84-01, Environmental Systems Application Center, Indiana University, Bloomington, Indiana.

Engel, S. 1990. Ecological impacts of harvesting macrophytes in Halverson Lake, Wisconsin. Journal of Aquatic Plant Management 28:41-45.

Environmental Systems Application Center. 1983. Coal Resources Fact Book. U.S. Geological Survey, Office of Earth Science Applications, Reston, Virginia.

EnviroScience. 2001. Results of August 16-17, 2000 bathymetric survey. EnviroScience, Inc., Stow, Ohio.

Ferraro, S.P. and F.A. Cole. 1995. Taxonomic level sufficient for assessing pollution impacts in Southern California Bight macrobenthos- revisited. Env. Tox. And Chem. 14:1021-1040.

Fink, D.F. 1994. A Guide to Aquatic Plants. Ecological Services Section, Minnesota Department of Natural Resources, Minneapolis, Minnesota.

Fox, J.L., P.L. Brezonik and M.A. Keirn. 1977. Lake Drawdown as a Method of improving Water Quality. EPA-600/3-77-005. U.S. Environ. Protec. Agency, Washington, D.C.

Furse et al. 1984. The influence of seasonal and taxonomic factors on the ordination and classification of running water sites in Great Britain and on the prediction of their macroinvertebrate communities. Freshwater Biology. 14:257-280.

Hasler, Arthur D. 1969. Cultural Eutrophication is Reversible. BioScience, 19(5):425-431

Held, T. 2000. Field Office HEL Data – Martin County, Indiana. U.S. Department of Agriculture, Natural Resources Conservation Service, Washington, Indiana.

Helsel, D.R., S.A. Nichols and R.S. Wakeman. 1999. Impact of aquatic plant management methods on Eurasian watermilfoil populations in southeast Wisconsin. J Lake and Reservoir Mgmt., 15(2): 159-167.

Hilsenhoff, William L. 1988. Rapid field assessment of organic pollution with a family-level biotic index. J. N. Am. Benthol. Soc. 7(1):65-68.

Hellmich, R.P. 2000. Report from the Indiana Natural Heritage Data Center for Lake Greenwood. Indiana Department of Natural Resources, Indianapolis, IN

Indiana Department of Environmental Management. 1996. Scoring criteria for the family level macroinvertebrate Index of Biotic Integrity (mIBI). Biological Studies Section, Indianapolis.

Jones, W.W., A. MacDonald, J.R. White, M.G. Wilder, D.E. Willard, T.M. Ross, T.J. Rillo and G. Robb. 1984. Griffy Lake Long-Range Use and Management Plan. ESAC-84-02. School of Public and Environmental Affairs, Indiana University, Bloomington, Indiana.

Jones, W.W. et al. 1997. Lake Monroe Diagnostic and Feasibility Study. School of Public and Environmental Affairs, Indiana University, Bloomington, Indiana.

Kadlec, R.H. and R.L. Knight. 1996. Treatment Wetlands. Lewis Publishers, Boca Raton, FL.

Lambert, H.R. 1997. Developing a Highway Access Policy – Guidelines and a Model Ordinance. Vermont Local Roads Program, Colchester, VT.

Landers, D.H. and D.G. Frey. 1980. The Dieback Role of *Myriophyllum spicatum* in Monroe Reservoir, Indiana. Technical Report No. 134. Purdue University Water Resources Research Center, West Lafayette, Indiana.

Livingston, E.H. 1989. Use of Wetlands for Urban Management. In: D.H. Hammer (Ed.), Constructed Wetlands for Wastewater Treatment – Municipal, Industrial and Agricultural. Lewis Publishers, Chelsea, MI.

Madsen, J.D. 2000. Advantages and disadvantages of aquatic plant management. LakeLine, 20(1): 22-34.

Marchant, R.L. et al. 1995. Influence of sample quantification and taxonomic resolution on the ordination of macroinvertebrate communities from running waters in Victoria, Australia. Marine and Freshwater Research. 46:501-506.

McCafferty, W.P. 1983. Aquatic Entomology: The Fisherman's and Ecologists' Illustrated Guide to Insects and Their Relatives. Jones and Bartlett Publishers, Inc., Boston.

McComas, S. 1986. Shoreline protection. Lake and Reservoir Management, 2:421-425.

McElrath, George, Jr. 1988. Soil Survey of Martin County, Indiana. U.S. Department of Agriculture, Soil Conservation Service.

Michigan Sea Grant Program. 1988. Vegetation and its Role in Reducing Great Lakes Shoreline Erosion. Michigan Sea Grant Communications, Ann Arbor, Michigan.

Mongin, M. 2001. Telephone interview.

Nichols, S.A. 1986. Innovative approaches for macrophyte management. Lake and Reservoir Management, 2:245-251.

Nichols, S.A. 1999. Distribution and habitat Descriptions of Wisconsin Lake Plants. Bulletin 96, Wisconsin Geological and Natural History Survey, Madison, Wisconsin.

Novotny, Vladimir and Harvey Olem. 1994. Water Quality: Prevention, Identification, and Management of Diffuse Pollution. Van Nostrand Reinhold, New York.

Ohio EPA. 1999. Association between nutrients, habitat, and the aquatic biota in Ohio rivers and streams. Ohio EPA Technical Bulletin MAS/1999-1-1, Columbus.

Orme, E.D. and D.W. Nelson. 1979. Chemistry of Phosphorus, Cadmium, Copper, Nickel, Lead, and Zinc in Indiana Lake and Reservoir Sediments. Technical Report No. 122, Water Resources Research Center, Purdue University, Lafayette, Indiana.

Prairie, Y.T. 1988. A test of the sedimentation assumptions of phosphorus input-output models. Arch. Hydrobiol., 111:321-327.

Prescott, G.W. 1982. Algae of the Western Great Lakes Area. Otto Koeltz Science Publishers, West Germany.

Reckhow, K.H. and J.T. Simpson. 1980. A procedure using modeling and error analysis for the prediction of lake phosphorus concentration from land use information. Can. J. Fish. Aquat. Sci., 37:1439-1448.

Reckhow, K.H., M.N. Beaulac and J.T. Simpson. 1980. Modeling Phosphorus Loading and Lake Response Under Uncertainty - A Manual and Compilation of Export Coefficients. EPA 440/5-80-011. U.S. Environmental Protection Agency, Washington, D.C.

Reed, R.L. and T.E. Rogers. 1991. A Good Neighbor: The First Fifty Years of Crane. Historic Indiana Project, University of Southern Indiana, Evansville.

Reichert, Melissa M. 1995. Vermont Better Backroads Manual – Clean Water You Can Afford. George D. Aiken & Northern Vermont Resource Conservation and Developments Councils, Brattleboro, VT.

SCS. 1968. SCS National Engineering Handbook, Section 3: Sedimentation. U.S. Department of Agriculture, Washington, D.C.

Soil Conservation Service. 1989. Standards and Specifications 580, Streambank and shoreline protection. Technical Guide Section IV. U.S. Department of Agriculture, Indianapolis, Indiana.

Stewart, J.A., C.R. Keeton, B.L., L.E. Hammil, H.T. Nguyen and D.K. Majors. 2000. Water Resources Data, Indiana, Water Year 1999. Water Data Report IN-99-1. U.S. Geological Survey, Indianapolis, Indiana.

Surprenant, Charles J. 1996. Fisheries Management Progress Report 1990-1995, Lake Greenwood. U.S. Fish and Wildlife Service, Fisheries Assistance Office, Carterville, IL.

Twenhofel W.H. 1950. Principles of Sedimentation, 2nd edition, McGraw-Hill Book Company, Inc.

USFWS. 2000. Draft 2000 Fisheries Management Report for Naval Weapons Support Center, Crane Division. Carterville Fishery Resources Office.

Vermont Local Roads. 1997. Cost-Effective Solutions to Protect Water Quality Near Vermont Town Roads. Saint Michael's College, Colchester, VT

Vollenweider, R.A. 1975. Input-output models - with special reference to the phosphorus loading concept in limnology. Scheirz. Zeits. Fur Hydrol., 37: 53-84).

Waite, I.R. et al. 2000. Comparing strengths of geographic and nongeographic classifications of stream benthic macroinvertebrates in the Mid-Atlantic Highlands, USA. J. N. Am. Benthol. Soc. 19(3):429-441.

Ward, H.B. and G.C. Whipple. 1959. Freshwater Biology, Second Edition. W.T. Edmondson, editor. John Wiley & Sons, Inc., New York.

Whitford, L.A. and G.J. Schumacher. 1984. A Manual of Fresh-Water Algae. Sparks Press, Raleigh, N.C.

APPENDIX A

Meeting Materials

Lake Greenwood, CRANE Public Meeting Comments & Questions

The Crane Project Staff sponsored a meeting to discuss the draft diagnostic study results on Monday, May 11 from 1:00 to 3:00 pm. Ten Crane and SAIC staff were in attendance (see list following) along with Bill Jones and Melissa Clark of Indiana University.

Mr. Jones presented a 45-minute Power Point program that highlighted the findings and recommendations of the study. A Fact Sheet (see Executive Summary sheet) was distributed to all in attendance. A summary of comments and questions are listed below.

<u>Comments</u>:

- There are two lumber mills within or at the edge of Lake Greenwood's watershed. The new one, Combs, is only a couple of years old.
- The milky substance could originate from the fire clay.
- The surrounding agricultural lands, now pasture and brush, was all small farms about 10 years ago.
- Fred Carr's Junk Yard, which is within the north edge of the watershed, has a pond to collect "whatever".
- The aquatic vegetation is just not there (in Lake Greenwood) this year.
- Culverts really need maintenance.

<u>Questions</u>:

- Do you think that the Eurasian Watermilfoil has already started to reduce?
- Does the shoreline erosion tend to gather around developments?
- What about wattling (slopes)?
- Anything about pH change? They want to look at rainfall vs. pH in order to keep the pH stable for drinking H_2O.
- If the chemical composition is going to change over time, then the drinking water plant must be prepared to make adjustments for drinking water?
- Are there any similarities with Yellowwood Lake, which was built in the same year under the re-establishment program?

Lake Greenwood Diagnostic Study Public Meeting
- Sign-In Sheet –

Name	Affiliation
Steve Andrews	Natural Resources
John Allen	SAIC
ANITA NETHERLAND	SAIC
LONNIE JACKSON	NSWC
Jim HUNSICKER	095 NSWC
JERRY HILL	09A NSWC
Tim Riggins	09 Zone 4 Basewide Support
Louis Warren	09Z5LW
SKIP LAWRENCE	0925
Gary Bradfield	SAIC

APPENDIX B

Data Sheets

Site #1

Ickiest Site OK

farthest from entrance

9-275 (Rev. 10-81)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER RESOURCES DIVISION

DISCHARGE MEASUREMENT NOTES

Meas. No. 5

Comp. by ~~Dots~~ Oxagas

Checked by

Sta. No.

Date 5/24/00, 19...... Party ......

Width ...... Area ...... Vel. ...... G. H. ...... Disch. ......

Method ...... No. secs. ...... G. H. change ...... in ...... hrs. Susp. ......

Method coef. ...... Hor. angle coef. ...... Susp. coef. ...... Meter No. ......

Type of meter ...... Date rated ...... Tag checked ......

Meter ...... ft. above bottom of wt. Spin before meas. ...... after ......

Meas. plots ...... % diff. from ...... rating. Levels obtained ......

GAGE READINGS

Time		Inside	ADR	Graphic	Outside
Weighted M.G.H.					
G. H. correction					
Correct M.G.H.					

WATER QUALITY MEASUREMENTS

No ...... Yes ...... Time ......

Samples Collected

No ...... Yes ...... Time ......

Method Used

EDI ...... EWI ...... Other ......

SEDIMENT SAMPLES

No ...... Yes ...... Time ......

Method Used

EDI ...... EWI ...... Other ......

BIOLOGICAL SAMPLES

Yes ...... Time ......

No ...... Type ......

Check bar, chain found ...... changed to ...... at ......

Wading, cable, ice, boat, upstr., downstr., side bridge ...... feet, mile, above, below gage.

Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%); based on the following cond:

Flow ......

Cross section ......

Control ......

Gage operating ...... Weather ......

Intake/Orifice cleaned ...... Air ...... °C@ ...... Water ...... °C@ ......

Record removed ...... Extreme Indicator: Max. ...... Min. ......

Manometer N_2 Pressure Tank ...... Feed ...... Bbl rate ...... per min.

CSG checked ...... Stick reading ......

Observer ......

HWM ...... outside, in well

Remarks ......

G.H. of zero flow ...... ft. Sheet No. ...... of ...... sheets

DO: 8.92 mg/l, Temp 19.50 Cond 137.5

River at—

Angle coefficient	Dist. from initial point	Width	Depth	Observation depth	Revolutions	Time in seconds	VELOCITY At point	VELOCITY Mean in vertical	Adjusted for hor. angle or	Area	Discharge

.0 .10 .20 .30 .40 .50 .60 .70 .75

.80 .85 .90 .92 .94 .96 .97 .98 .99 1.00 .99 .98 .97 .96 .94 .92 .90 .85 .80

Stream #2

Fish

9-275-F
(Rev. 10-81)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER RESOURCES DIVISION

DISCHARGE MEASUREMENT NOTES

Meas. No. . . . . . .

Comp. by . . . . . .

Checked by . . . . .

Sta. No.

Date 5/24/00 , 19 . . . . . . Party . . . .

Width . . . Area . . . . Vel. . . . . . . G. H. . . . . Disch. . . . .

Method . . . No. secs. . . . . G. H. change . . . . . in . . . . . hrs. Susp. . . . . . .

Method coef. . . . Hor. angle coef. . . . . Susp. coef. . . . . Meter No. . . . . . .

Type of meter . . . . Date rated . . . . Tag checked . . . .

Meter . . . . ft. above bottom of wt. Spin before meas. . . . . after . . . .

Meas. plots . . . . % diff. from . . . . rating. Levels obtained . . . .

GAGE READINGS

Time		Inside	ADR	Graphic	Outside
Weighted M.G.H.					
G. H. correction					
Correct M.G.H.					

WATER QUALITY MEASUREMENTS

No . . . . . . Yes. . . . . . Time . . . . . .

Samples Collected

No . . . . . . Yes. . . . . . Time . . . . . .

Method Used

EDI . . . . . EWI . . . . . Other. . . . . .

SEDIMENT SAMPLES

No . . . . . . Yes. . . . . . Time . . . . . .

Method Used

EDI . . . . . EWI . . . . . Other. . . . . .

BIOLOGICAL SAMPLES

Yes. . . . . Time . . . .

No . . . . Type . . . .

Check bar, chain found . . . . changed to . . . . at . . . .

Wading, cable, ice, boat, upstr., downstr., side bridge . . . . . feet, mile, above, below gage.

Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%); based on the following cond:

Flow . . . .

Cross section . . . .

Control . . . .

Gage operating . . . . Weather . . . .

Intake/Orifice cleaned . . . . . Air . . . . . °C@ . . . . . Water . . . . . . °C@ . . . . . .

Record removed . . . . Extreme Indicator: Max. . . . . Min. . . . .

Manometer N_2 Pressure Tank . . . . . . Feed . . . . Bbl rate . . . . per min.

CSG checked . . . . Stick reading . . . .

Observer . . . .

HWM . . . . outside, in well

Remarks . . . .

G. H. of zero flow . . . . ft. Sheet No. . . . . of . . . . sheets

River at— m/s ft/s

Angle coefficient	Dist. from initial point	Width	Depth	Observation depth	Revolutions	Time in seconds	Velocity At point	Velocity Mean in vertical	Adjusted for hor. angle or	Area	Discharge
0.4	0.5	0.2	0.25				0.033	0.10			0.005
0.6	0.7	0.2	0.25				0.25	0.82			0.041
0.8	0.9	0.2	[illegible]				[illegible]	0.52			0.0312
1.0	1.1	0.2	0.35				0.07	0.23			0.0161
1.2	1.3	0.2	0.25				0.07	0.23			0.0115
1.4	1.5	0.2	0.23				[illegible]	0.20			0.0092
1.6											

TOTALS 0.1140

Stream #3 smallest

Closest to entrance

9-275-F (Rev. 10-81) — DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER RESOURCES DIVISION
DISCHARGE MEASUREMENT NOTES

Meas. No. ......
Comp. by 10:50
Checked by ......

Sta. No. ......

Date 5/25/00, 19...... Party ......
Width 3.6 Area ...... Vel. ...... G. H. ...... Disch. ......
Method ...... No. secs. ...... G. H. change ...... in ...... hrs. Susp. ......
Method coef. ...... Hor. angle coef. ...... Susp. coef. ...... Meter No. ......
Type of meter Flow Mate Date rated ...... Tag checked ......
Meter ...... ft. above bottom of wt. Spin before meas. ...... after ......
Meas. plots ...... % diff. from ...... rating. Levels obtained ......

GAGE READINGS					
Time		Inside	ADR	Graphic	Outside
Weighted M.G.H.					
G. H. correction					
Correct M.G.H.					

WATER QUALITY MEASUREMENTS
No ...... Yes ...... Time ......

Samples Collected
No ...... Yes ...... Time ......

Method Used
EDI ...... EWI ...... Other ......

SEDIMENT SAMPLES
No ...... Yes ...... Time ......

Method Used
EDI ...... EWI ...... Other ......

BIOLOGICAL SAMPLES
Yes ✓ ...... Time ......
No ...... Type Multihabitat

0.2 → 3.8 total 3.6

Check bar, chain found ...... changed to ...... at ......
Wading, cable, ice, boat, upstr., downstr., side bridge ...... feet, mile, above, below gage.
Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%); based on the following cond:
Flow ......
Cross section ......
Control ......
Gage operating ...... Weather sunny & warm
Intake/Orifice cleaned ...... Air ...... °C@ ...... Water ...... °C@ ......
Record removed ...... Extreme Indicator: Max. ...... Min. ......
Manometer N_2 Pressure Tank ...... Feed ...... Bbl rate ...... per min.
CSG checked ...... Stick reading ......
Observer ......
HWM ...... outside, in well
Remarks definitely observed some flow, however, it is VERY low as the results indicate.

G H of zero flow ...... ft. Sheet No. ...... of ...... sheets

Temp 17.1°C, DO-9.45mg/l Cond-...

River at—

Angle coefficient	Dist. from initial point	Width	Depth	Observation depth	Revolutions	Time in seconds	Velocity At point	Velocity Mean in vertical	Adjusted for hor. angle or	Area	Discharge
0.2	0.6	0.6	0.85				0				0
0.8	1.0	0.4	1.35				0				0
1.2	1.4	0.4	1.35				0				0
1.6	1.8	0.4	1.05				0				0
2.0	2.2	0.4	0.7				0				0
2.4	2.6	0.4	0.5				0.1				0.0468
2.8	3.0	0.4	0.4				0				0
	3.4	0.4									

TOTAL 0.0468

LAKE ASSESSMENT FIELD DATA SHEET

SITE: Greenwood Stream #1

DATE: 8/8/00 TIME: 3:00pm WEATHER: cloudy, 85°

DEPTH (m)	TEMP (°C)	D.O. sat (%)	D.O (ppm)
Sur	17.2		9.25
1.0			
1.5			
2.0			
3.0			
4.0			
5.0			
6.0			
7.0			
8.0			
9.0			
10.0			
11.0			
12.0			
13.0			
14.0			
15.0			
16.0			
17.0			
18.0			

	E	H
COND	60	
% TRANSM. @ 3' =		
1% level (ft) =		
SECCHI (m) =		
ANCHOR DEPTH (ft & m)		
HYPO (m)		
PLANKTON TOW (m)		
CHL *a* FILTERED (ml)		

Shoreline Development

Homes/Structures:

Wetlands:

Forest/Shrubs:

Park Land:

Agriculture:

RAMP TYPE:

Latitude:

Longitude:

INITIALS:

COMMENTS:

(Rev 10-81)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER RESOURCES DIVISION

Meas. No. ......

Comp. by ......

Sta. No.

DISCHARGE MEASUREMENT NOTES

Checked by ......

Crane Project Stream #1

Date 4/6/00, 19 00 Party Jones/Clark

Width ...... Area ...... Vel. ...... G. H. ...... Disch. ......

Method ...... No. secs. ...... G. H. change ...... in ...... hrs. Susp. ......

Method coef. ...... Hor. angle coef. ...... Susp. coef. ...... Meter No. ......

Type of meter ...... Date rated ...... Tag checked ......

Meter ...... ft. above bottom of wt. Spin before meas. ...... after ......

Meas. plots ...... % diff. from ...... rating. Levels obtained ......

GAGE READINGS					
Time		Inside	ADR	Graphic	Outside
Weighted M.G.H.					
G. H. correction					
Correct M.G.H.					

WATER QUALITY MEASUREMENTS

No ...... Yes ...... Time ......

Samples Collected

No ...... Yes ...... Time ......

Method Used

EDI ...... EWI ...... Other ......

SEDIMENT SAMPLES

No ...... Yes ...... Time ......

Method Used

EDI ...... EWI ...... Other ......

BIOLOGICAL SAMPLES

Yes ...... Time ......

No ...... Type ......

Check bar, chain found ...... changed to ...... at ......

Wading, cable, ice, boat, upstr., downstr., side bridge ...... feet, mile, above, below gage.

Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%); based on the following cond:

Flow ......

Cross section ......

Control ......

Gage operating ...... Weather ......

Intake/Orifice cleaned ...... Air ...... °C@ ...... Water ...... °C@ ......

Record removed ...... Extreme Indicator: Max. ...... Min. ......

Manometer N_2 Pressure Tank ...... Feed ...... Bbl rate ...... per min.

CSG checked ...... Stick reading ......

Observer ......

HWM ...... outside, in well

Remarks ......

G.H. of zero flow ...... ft. Sheet No. ...... of ...... sheets

River at—

	Angle coefficient	Dist. from initial point	Width m	Depth ft	Observation depth	Revolutions	Time in seconds	VELOCITY At point	VELOCITY Mean in vertical	Adjusted for hor. angle or	Area	Discharge
REW		0.3m						fps				
		0.6	0.6	2.5				.63				3.04
		1.2	0.6	2.6				1.03				5.22
		1.8	0.6	3.1				1.30				7.86
		2.4	0.6	3.2				1.38				8.61
		3.0	0.6	2.1				1.04				6.29
		3.6	0.6	3.0				1.02				5.97
		4.2	0.6	2.9				0.63				3.56
		4.8	0.6	2.7				0.44				2.32
		5.4	0.6	2.2				0.24				1.03
		6.0	0.6	1.9				0.08				0.3
		6.6	0.6	1.6				–				0
		7.2	0.9	1.05				–				0

0.6m = 1.95ft

Total 44.22

7.8m

0

LAKE ASSESSMENT FIELD DATA SHEET

SITE: Greenwood Stream #2

DATE: 8/8/00 TIME: 4:15 WEATHER: cloudy, calm, 85

DEPTH (m)	TEMP (°C)	D.O. sat (%)	D.O (ppm)
Sur	17.2		10.1
1.0			
1.5			
2.0			
3.0			
4.0			
5.0			
6.0			
7.0			
8.0			
9.0			
10.0			
11.0			
12.0			
13.0			
14.0			
15.0			
16.0			
17.0			
18.0			

E H

COND 74

% TRANSM. @ 3' =

1% level (ft) =

SECCHI (m) =

ANCHOR DEPTH (ft & m)

HYPO (m)

PLANKTON TOW (m)

CHL *a* FILTERED (ml)

Shoreline Development

Homes/Structures:

Wetlands:

Forest/Shrubs:

Park Land:

Agriculture:

RAMP TYPE:

Latitude:

Longitude:

INITIALS:

COMMENTS:

9-275-F (Rev. 10-81)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER RESOURCES DIVISION

DISCHARGE MEASUREMENT NOTES

4:15 PM

Meas. No. ......
Comp. by ......
Checked by ......

Sta. No. ...... Grace Street [illegible]

Date 8/8/ 2000 ...... Party Clark/Jones

Width ...... Area ...... Vel. ...... G. H. ...... Disch. ......

Method ...... No. secs. ...... G. H. change ...... in ...... hrs. Susp. ......

Method coef. ...... Hor. angle coef. ...... Susp. coef. ...... Meter No. ......

Type of meter ...... Date rated ...... Tag checked ......

Meter ...... ft. above bottom of wt. Spin before meas. ...... after ......

Meas. plots ...... % diff. from ...... rating. Levels obtained ......

GAGE READINGS					
Time		Inside	ADR	Graphic	Outside
Weighted M.G.H.					
G. H. correction					
Correct M.G.H.					

WATER QUALITY MEASUREMENTS

No ...... Yes ...... Time ......

Samples Collected

No ...... Yes ...... Time ......

Method Used

EDI ...... EWI ...... Other ......

SEDIMENT SAMPLES

No ...... Yes ...... Time ......

Method Used

EDI ...... EWI ...... Other ......

BIOLOGICAL SAMPLES

Yes ...... Time ......

No ...... Type ......

Check bar, chain found ...... changed to ...... at ......

Wading, cable, ice, boat, upstr., downstr., side bridge ...... feet, mile, above, below gage.

Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%); based on the following cond:

Flow ......

Cross section ......

Control ......

Gage operating ...... Weather ......

Intake/Orifice cleaned ...... Air ...... °C@ ...... Water ...... °C@ ......

Record removed ...... Extreme Indicator: Max. ...... Min. ......

Manometer N_2 Pressure Tank ...... Feed ...... Bbl rate ...... per min.

CSG checked ...... Stick reading ......

Observer ......

HWM ...... outside, in well

Remarks ......

G.H. of zero flow ...... ft. Sheet No. ...... of ...... sheets

River at—

	Angle coefficient	Dist. from initial point	Width m	Depth ft	Observation depth	Revolutions fps	Time in seconds	Velocity At point	Velocity Mean in vertical	Adjusted for hor. angle or	Area	Discharge
REW		0.5										
		0.7	0.4	1.0		—						0
		1.1		1.2		2.04						3.18
		1.5		1.3		2.34						3.95
		1.9		1.4		3.01						5.48
		2.3		1.6		2.03						4.22
		2.7		1.5		2.23						4.35
		3.1		1.4		2.27						4.13
		3.5		1.3		1.96						3.31
		3.9	0.4	1.3		0.97						1.64
		4.3	0.4	1.6		0.16						0.33
		4.7	0.4	1.8		0.43						1.01
		5.1	0.5	1.5		0.06						0.15
			0.4m = 1.3 ft									
			0.5m = 1.65 ft							Total		31.75
LEW		5.4										

LAKE ASSESSMENT FIELD DATA SHEET

SITE: Greenwood Stream #3

DATE: 8/8/00 TIME: 5:00 WEATHER: ______

DEPTH (m)	TEMP (°C)	D.O. sat (%)	D.O (ppm)
Sur	17.0		8.9
1.0			
1.5			
2.0			
3.0			
4.0			
5.0			
6.0			
7.0			
8.0			
9.0			
10.0			
11.0			
12.0			
13.0			
14.0			
15.0			
16.0			
17.0			
18.0			

	E	H
COND	78	
% TRANSM. @ 3' =		
1% level (ft) =		
SECCHI (m) =		
ANCHOR DEPTH (ft & m)		
HYPO (m)		
PLANKTON TOW (m)		
CHL *a* FILTERED (ml)		

Shoreline Development

Homes/Structures: ______

Wetlands: ______

Forest/Shrubs: ______

Park Land: ______

Agriculture: ______

RAMP TYPE: ______

Latitude: ______

Longitude: ______

INITIALS: ______

COMMENTS:

(Rev. 10-81)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER RESOURCES DIVISION

Meas. No. . . . .

Comp. by. . . . . . .

Checked by . . . . . .

DISCHARGE MEASUREMENT NOTES

Sta. No. Greenwood Stream #3

Date 8/8, 19 00. . Party Clark/Jones

Width . . . . Area. . . . . . Vel. . . . . . G. H. . . . . Disch. . . . .

Method . . . No. secs. . . . G. H. change. . . . . . in . . . . . hrs. Susp. . . . . . .

Method coef. Hor. angle coef. . . . . Susp. coef. . . . . Meter No. . . . .

Type of meter . . Date rated . . . . Tag checked . . . .

Meter . . . ft. above bottom of wt. Spin before meas. . . . . after . . . .

Meas. plots . . . % diff. from. . . . rating. Levels obtained. . . . .

GAGE READINGS					
Time		Inside	ADR	Graphic	Outside
Weighted M.G.H.					
G. H. correction					
Correct M.G.H.					

WATER QUALITY MEASUREMENTS

No . . . . . . Yes. . . . . . Time . . . . . .

Samples Collected

No . . . . . . Yes. . . . . . Time . . . . . .

Method Used

EDI . . . . . EWI . . . . . Other. . . . . .

SEDIMENT SAMPLES

No . . . . . . Yes. . . . . . Time . . . . . .

Method Used

EDI . . . . . EWI . . . . . Other. . . . . .

BIOLOGICAL SAMPLES

Yes. . . . . Time . . . .

No . . . . Type . . . .

Check bar, chain found . . . . changed to . . . . at . . . .

Wading, cable, ice, boat, upstr., downstr., side bridge. . . . . feet, mile, above, below gage.

Measurement rated excellent (2%), good (5%), fair (8%), poor (over 8%); based on the following cond:

Flow . . . .

Cross section . . . .

Control . . . .

Gage operating . . . . Weather . . . .

Intake/Orifice cleaned . . . . Air . . . . . °C@ . . . . Water . . . . . °C@ . . . . . .

Record removed . . . . Extreme Indicator: Max. . . . . Min. . . . .

Manometer N_2 Pressure Tank . . . . . Feed . . . . Bbl rate . . . . per min.

CSG checked . . . . Stick reading . . . .

Observer . . . .

HWM . . . . outside, in well

Remarks . . . .

G.H. of zero flow . . . . ft. Sheet No. . . . . of . . . . sheets

River at—

	Angle coefficient	Dist. from initial point	Width	Depth	Observation depth	Revolutions	Time in seconds	VELOCITY At point	VELOCITY Mean in vertical	Adjusted for hor. angle or	Area	Discharge
REW		0.5	m	[illegible]				[illegible]				
		0.7	0.4	0.4				0.55				0.29
		1.1		0.9				0.85				1.03
		1.5		[illegible]				[illegible]				1.58
		1.9		[illegible]				0.88				2.23
		2.3		[illegible]				[illegible]				2.72
		2.7		1.55				0.97				3.67
		3.1	[illegible]	3.1				1.10				4.43
		3.5	0.2	1.2				1.03				1.21
											Total	17.15
				0.3m=0.975ft								
				0.4m= 1.3ft								
LEW		3.6										

LAKE ASSESSMENT FIELD DATA SHEET

SITE: Lake Greenwood

DATE: 8/16/00 TIME: 4:00 WEATHER: clear 0-5, 85°

DEPTH (m)	TEMP (°C)	D.O. sat (%)	D.O (ppm)
Sur	29.8		7.3
1.0	29.5		7.3
1.5	29.3	95.8	7.4
2.0	28.2		7.5
3.0	27.7		7.2
4.0	26.4		5.7
5.0	23.1		1.0
6.0	20.2		1.3
7.0	17.5		0.7
8.0	15.7		0.7
9.0	14.9		0.7
10.0	13.5		0.7
11.0	12.3		0.7
12.0			
13.0			
14.0			
15.0			
16.0			
17.0			
18.0			

	E	H
COND	108	101
% TRANSM. @ 3' =		55%
1% level (ft) =		18'
SECCHI (m) =		3.3
ANCHOR DEPTH (ft & m)		38' 11.6
HYPO (m)		9.5
PLANKTON TOW (m)		5.0
CHL *a* FILTERED (ml)		1480

Shoreline Development

Homes/Structures:	
Wetlands:	
Forest/Shrubs:	98%
Park Land:	2%
Agriculture:	

RAMP TYPE: Concrete

Latitude: N 38° 53' 5.9"

Longitude: W 86° 52' 7.8"

INITIALS: WWJ

COMMENTS:

PLANKTON DATA

NAME Jan Hosier SAMPLE DATE 8-17-00 TOW LENGTH 5 m DIAMETER OF FIELD 1.34

LAKE Greenwood COUNTY ______ SAMPLE VOL. 37+4=41mL DEVICE Tow Net

	SPECIES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTAL COUNT	#/L	MEAN VOL
D	Dinobryon	9	6	6	6	8	8	6	2	5	7	8	4	5	9	9	98	517	
B	Anabaena	2	10	9	23	7	15	6	2	9	4	25	17	6	6	3	144	751	
B	Microcystis	2	0	3	1	–	3	–	–	–	–	2	–	–	–	–	11	57	
G	Ulothrix	1	0	–	0	–	–	–	–	–	–	1	–	1	–	–	3	16	
O	Chrysosphaerella	1	1	1	2	1	1	2	3	1	3	2	4	1	3	2	28	148	
R	Misc Rotifer	–	–	2	6	1	3	1	–	4	3	7	–	2	5	1	35	184	
D	Fragilaria	–	–	–	1	–	–	–	–	–	1	1	–	–	–	–	3	16	
D	Ceratium	–	–	–	–	1	–	–	–	–	3	1	–	1	–	–	6	32	
B	Coelosphaerium	–	–	–	–	–	–	1	–	–	–	–	–	–	1	–	2	11	
G	Staurastrum	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	[illegible]	5	
G	Misc. Green	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–		5	
B	Oscillatoria	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	[illegible]	11	
R	Keratella	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	5	
Z	Diaphanosoma	|															1	0.1	
Z	Bosmina	||															2	0.2	
Z	Nauplii	卌	卌	卌	卌	卌	卌	卌	||								34	4.4	
Z	Calanoid	卌	卌	卌	|||												18	2.2	
Z	Cyclopoid	卌	卌														10	1.2	
Z	Daphnia	卌	|||														8	1.0	
Z	Leptodora	||||															4	0.5	
Z	Misc Zooplankton	卌															5	0.6	

TOTALS

B= 833

G= 26

D= 16

O= 64[illegible]

R= 1[illegible]

Z= 10.2

Total= 1796

% B-G= [illegible]

PLANKTON DATA

NAME Theresa Wilson SAMPLE DATE 8-17-00 TOW LENGTH 5m DIAMETER OF FIELD 1.24

LAKE Greenwood COUNTY Martin SAMPLE VOL. 42mL DEVICE tow net

	SPECIES	FIELDS 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTAL COUNT	#/L	MEAN VOL
O	Dinobryon	7	9	12	3	5	4	4	5	2	6	4	4	5	4	1	75	403	
G	Ulothrix	1	—	—	—	—	—	—	—	—	—	1	—	—	1	—	3	16	
O	Chrysosphaerella	3	3	4	3	2	2	2	3	2	4	3	3	2	2	1	39	211	
BG	Anabaena	1	2	3	2	6	2	7	6	3	5	7	6	5	3	7	65	351	
O	Ceratium	—	1	—	—	—	1	1	—	—	1	1	—	—	1	1	7	38	
O	Misc. Protozoa	–	4	—	—	2	—	2	—	—	1	—	—	—	—	—	9	49	
R	Rotifera	1	—	—	1	—	2	1	4	—	1	—	2	2	1	1	16	86	
R	Keratella	—	—	—	—	—	—	—	1	—	—	—	—	—	—	1	2	11	
D	Fragilaria		—	—	—	—	—	—	—	—	—	—	1	—	—	—	1	5	
Z	Nauplii	||||| |||||	||||| |||||	||||| |||||	||||| |||||													41	5.6	
Z	Diaphanosoma	|||															2	0.3	
Z	Calanoid	||||| |||||	||||| ||														17	2.1	
Z	Cyclopoid	||||| |||||															10	1.2	
Z	Daphnia	||||| |||||															10	1.2	
Z	Bosmina	||															2	0.3	

TOTALS

B= 351

G= 16

D= 5

O= 713

R= 97

Z= 10.1

Total= 1193

% B-G= 31.1%